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Engineering Division

Technical Release No. 50
Design Unit
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DESIGN OF RECTANGULAR STRUCTURAL CHANNELS

PREFACE

This technical release continues the effort to produce design aids which facilitate the attempt towards optimization of structural design. Three earlier technical releases, TR-42, TR-43, and TR-45, deal with the structural design of rectangular conduits. This technical release is concerned with the structural design of rectangular channels. Although primarily written for design engineers, the material has considerable application for planning engineers since preliminary designs of structural channels are readily available to them.

A draft of the subject technical release dated August, 1971, was sent to the Engineering and Watershed Planning Unit Design Engineers for their review and comment.

This technical release was prepared by Mr. Edwin S. Alling of the Design Unit, Design Branch at Hyattsville, Maryland. He also wrote the computer program.

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NOMENCLATURE

Not all nomenclature is listed. Hopefully, the meaning of any unlisted nomenclature may be ascertained from that shown.

A	≡ required reinforcing steel area
ACOMP	≡ required compressive steel area in strut
AE	≡ equivalent edge beam steel area per foot width
AG	≡ gross area of strut
ATENS	≡ required tensile steel area in T1S strut; required tensile steel through T3FV shear joint
AV	≡ area of web steel, equals twice bar area
a	≡ distance from point A to beginning of load on infinite beam
B	≡ clear width of channel
BPGR	= (B + TB/12)
b	≡ width of reinforced concrete member; distance from point A to end of loading on infinite beam
C	≡ JOINTS; distance to extreme fiber
CB	≡ direct compressive force in floor slab between walls
CF	≡ direct compressive force in the footing projection
CFSC	≡ coefficient of friction, soil to concrete
CFSS	≡ coefficient of friction, soil to soil
c	≡ distance from point A to left end of load on infinite beam
D	≡ effective depth of concrete section; diameter of reinforcing bar
E	≡ eccentricity of VNET; eccentricity of RC due to M_D; modulus of elasticity of concrete
EB	≡ width of edge beam
ET	≡ thickness of edge beam
e	≡ distance from point A to right end of load on infinite beam
FKEY	≡ horizontal force acting on key wall
FLOATR	≡ safety factor against flotation
FTG	≡ footing projection
f_c	≡ compressive stress in concrete
f_s	≡ stress in reinforcing steel
GBUOY	= GSAT - 62.4
GMOIST	≡ moist unit weight of backfill
GSAT	≡ saturated unit weight of backfill
HB	≡ height of backfill above top of floor slab
HBD	= (HB - D/12)
HC	= (HT - EB/12)
HDIFF	= (HB - HW1) or (HB - HW2)
HIN	≡ horizontal force of water in channel on retaining wall portion of channel
H_i	≡ components of horizontal load on the wall
HKEY	≡ additional lateral earth force caused by key wall
HR	≡ sum of resisting horizontal forces on retaining wall portion of channel
HS	= (HB + TS/12)
HT	≡ height of wall above top of floor slab
HTB	= (HT - HB)

HTW = (HT - HW1)
HW = (HW1 + TS/12)
HW1 ≡ submergence height above top of floor slab for LC#1
HW2 ≡ submergence height above top of floor slab for LC#2
HWALL ≡ total horizontal loading on the wall
HWD = (HW1 - D/12)
HWP ≡ uplift head on pavement slab
I ≡ moment of inertia
J = (FTG + TB/24)
JOINTS ≡ longitudinal span between transverse joints

j ≡ ratio used in reinforced concrete design
K ≡ MFOUND
KO1 ≡ lateral earth pressure ratio for LC#1
KO2 ≡ lateral earth pressure ratio for LC#2
KPASS ≡ passive lateral earth pressure ratio
L ≡ span of finite beam
LC#1 ≡ load condition number one
LC#2 ≡ load condition number two
M ≡ bending moment at section under investigation
MAXFTG ≡ maximum acceptable footing projection

MB ≡ simple moment due to PGR on B
MBP ≡ simple moment due to PGR on BPGR
MC = (MWALL + MFTG)
MD ≡ maximum dead load moment in strut
ME ≡ equivalent edge beam moment per foot width
MFOUND ≡ modulus of the foundation
MFTG ≡ moment at junction of stem wall and footing projection due to loads on footing projection
MKEY ≡ key wall design moment
M_o ≡ overturning moment about toe of retaining wall portion of channel; ficticious moment at ends of finite beam on elastic foundation
MR = (MBP - MB)

M_r ≡ resisting moment about toe of retaining wall portion of channel
M_s ≡ equivalent moment, moment about axis at the tension steel
MSUP ≡ supplemental moment added to end of finite beam when $0 < ZPOS \leqq J$
MW ≡ simple moment due to water in channel; moment applied to floor slab at wall
MWALL ≡ moment at junction of stem wall and footing projection due to loads on wall
MZ ≡ moment in wall at Z below top of wall
m ≡ T/U, T1S frame constant
N ≡ direct force at section under investigation
NSHT ≡ assumed direct compressive force in pavement slab due to water in channel
NW ≡ concentrated load applied to floor slab at wall

NWALL ≡ direct force brought by the wall to the floor slab of T1S channel

NX = RC/RX
NY = RC/RY
NZ ≡ direct force in wall at Z below top of wall
n ≡ 1/U, T1S frame constant
P ≡ intergranular bearing pressure; foundation pressure
P1 ≡ bearing (contact) pressure at toe of retaining wall base
P11 ≡ P1 for LC#1
P2 ≡ bearing (contact) pressure at heel of retaining wall base
PALLOW ≡ maximum allowable bearing (contact) pressure

PB ≡ uniform loading on floor slab between walls
PD ≡ bearing (contact) pressure at D from face of support
PF ≡ bearing (contact) pressure at face of support; uniform loading on footing portions of floor slab
PFTG ≡ overburden pressure on footing projection
PGR ≡ gross pressure on T1S floor slab
PS ≡ uniform loading causing shear in floor slab
PUP ≡ uplift pressure on bottom of slab
P_t ≡ temperature and shrinkage steel ratio
Q ≡ shear transmitted across the joint between pavement slab and retaining wall base of T3FV channel
Q1 ≡ Q for LC#1

Q_o ≡ ficticious shear at ends of finite beam on elastic foundation
QSUP ≡ supplemental shear added to end of finite beam when $0 < ZPOS \leq J$
q ≡ uniform loading on infinite beam
R ≡ ratio of downward forces on channel to the uplift forces
RC ≡ maximum compressive force in strut maximum
RS ≡ edge beam reaction provided by strut
RS1 ≡ RS for LC#1
RT ≡ maximum tensile force in strut
RX ≡ edge beam loading; correction factor for long column buckling about X axis
RX1 ≡ RX for LC#1

RX1MAX ≡ maximum value of any RX1
RX1MIN ≡ minimum value of any RX1
RY ≡ correction factor for long column buckling about Y axis
S ≡ maximum allowable spacing of reinforcing steel
SB ≡ width of strut
ST ≡ thickness of strut
SZ ≡ maximum allowable spacing of steel at Z below top of wall
T ≡ thickness of section under investigation; displacement at top of T1S frame with struts removed
TB ≡ thickness of bottom of wall at floor slab
TKEY ≡ thickness of key wall

TP ≡ thickness of pavement slab
TS ≡ thickness of floor slab or base slab
TT ≡ thickness of top of wall
t ≡ thickness of frame at y
U ≡ displacement at top of T1S frame due to unit loads
u ≡ flexural bond stress in concrete

V ≡ shear force at section under investigation
VD ≡ shear force at D from face of support
VE ≡ buoyant weight of soil beneath retaining wall base in depth ZKEY

VF ≡ shear force at face of support
VNET ≡ sum of vertical forces including uplift
VPR ≡ shear carried by web steel
VZ ≡ shear in wall at Z below top of wall
v ≡ shear stress in concrete
W ≡ width of a retaining wall portion of T3F or T3FV channel
WO ≡ overall width of channel
WP ≡ bearing pressure at end of pavement slab
WP1 ≡ WP for LC#1
WRT ≡ reaction at top of wall
X ≡ toe length of T3F and T3FV walls; reference edge beam coordinate

XD = (X - D/12)
XF = (X + TB/12)
XP ≡ width of pavement slab between retaining wall bases
x ≡ distance from point A to element of load on infinite beam
Y ≡ displacement; distance from center of retaining wall base to point under investigation
YD = (W/2 - XD)
YF = (W/2 - XF)
Y_o ≡ displacement at load point in alternate method of edge beam analysis
YX ≡ displacement at Z from end in actual edge beam
YZ ≡ displacement at Z from end in alternate method of edge beam anaylsis

y ≡ distance from mid-depth of edge beam to point under consideration in frame
Z ≡ distance from VNET to toe of retaining wall portion of channel; distance from edge of finite beam to point A
ZKEY ≡ depth of key wall below retaining wall base
ZPOS ≡ distance from end of finite beam to point of zero reactive pressure
β ≡ $\left(\frac{n}{4EI}\right)^{1/4}$; $\left(\frac{5184K}{E(TS)^3}\right)^{1/4}$
$\beta\ell$ ≡ a length parameter in theory of beams on elastic foundations
ΔQ ≡ additional shear required to produce equal vertical displacements each side of joint
Δs ≡ incremental length along axis of frame
δ ≡ vertical displacement
δ_b ≡ vertical displacement of retaining wall base at joint between pavement slab and retaining wall base
δ_p ≡ vertical displacement of pavement slab at joint between pavement slab and retaining wall base
$\zeta(x)$ ≡ functional relation in theory of beams on elastic foundations
$\theta(x)$ ≡ functional relation in theory of beams on elastic foundations
$\phi(x)$ ≡ functional relation in theory of beams on elastic foundations
$\psi(x)$ ≡ functional relation in theory of beams on elastic foundations
Σo ≡ required perimeter of reinforcing steel
λ ≡ coefficient relating Q to bearing pressure at end of pavement slab

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DESIGN OF RECTANGULAR STRUCTURAL CHANNELS

Introduction

This work is concerned with the structural design of reinforced concrete rectangular channels. It assumes these structural channel designs will be obtained from computers although the basic approach is independent of computer usage. The material presented herein applies to components such as rectangular lined channels through urban areas, chute spillway channels, rectangular flumes, and elements of stilling basins.

A computer program was written in FORTRAN for IBM 360 equipment to perform this design task. The program operates in two modes. It will execute rapid preliminary designs to aid the designer in selecting the type of structural channel he desires to use in final design. The program will also execute the detail design of the specified channel. Concrete thicknesses and distances are determined and required steel areas and spacings are evaluated. Actual steel sizes and layouts are not determined, these are the prerogative of the designer.

This work documents the criteria and procedure used in the computer program, explains the input data required to obtain a design, and illustrates computer output for preliminary and detail designs. At the present time designs may be obtained by requests to the

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The input information discussed under the section, "Computer Designs, Input" must be provided for each design run desired.

Types of Structural Channels

Four structural channel types are treated herein. All are assumed symetrical about the channel centerline in both construction and loading. Each channel is designed for the two loading conditions described in the next section and each must satisfy flotation (uplift) requirements. See Figure 1 for definition sketches. Any one of the four types may be most advantageous for a particular set of design conditions. Because of the large number of parameters involved, it is not always readily apparent which type will be best in a given situation.

Type T1F

In this type, the walls and floor slab constitute a reinforced concrete U-shaped rigid frame. The cantilever walls are integral with the floor slab.

Type T3F

In this type, the walls are designed as reinforced concrete cantilever retaining walls. The most advantageous toe length, X, is determined in the design. The pavement slab between the retaining wall bases, is independent of the bases.

Type T3FV

This is similar to type T3F except that the joints between the pavement slab and the retaining wall bases are designed to transmit shear forces. This type might be used instead of type T3F, when foundation conditions are such that large relative vertical displacements between the pavement slabs and the retaining wall bases could be expected using type T3F, and these relative displacements would be considered objectionable. Thus in type T3FV the pavement slab and retaining wall base deflect equally at the joints.

Type T1S

This is similar to type T1F except that two reinforced concrete struts are provided in each longitudinal span between transverse joints. The struts are located at the first interior quarter points of the longitudinal span. Edge beams are provided along the tops of the channel walls. Thus the walls are not simple cantilevers from the base as with the other types, instead they are supported by the edge beam and strut system and by the floor slab.

Loading Conditions

Two loading conditions are considered in the design of structural channels. Parameter values should be selected so that these loading conditions reflect extremes of probable conditions.

Load Condition No. 1

In this loading the channel is empty. The backfill is submerged to a height, HW1, above the top of the floor slab. The backfill is naturally drained, i.e., moist, above HW1. Load condition No. 1 is meant to

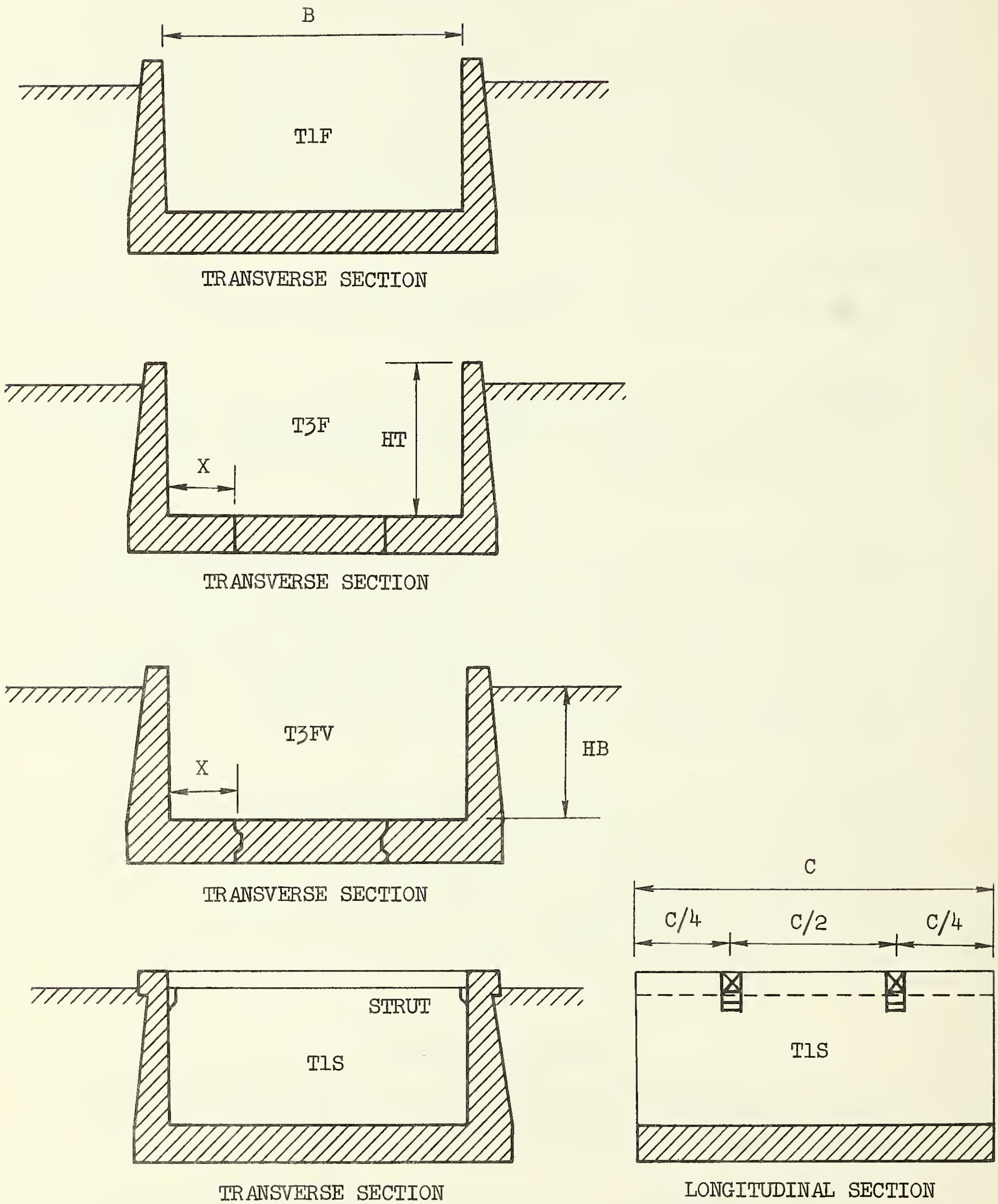


Figure 1. Structural channel types.

represent conditions following a rapid lowering of the water surface in the channel, but before the water table in the backfill has lowered significantly from a high level. Thus this loading should maximize: lateral soil load, lateral water load, and uplift. The lateral pressure ratio, KO1, should be taken as high as can reasonably be expected.

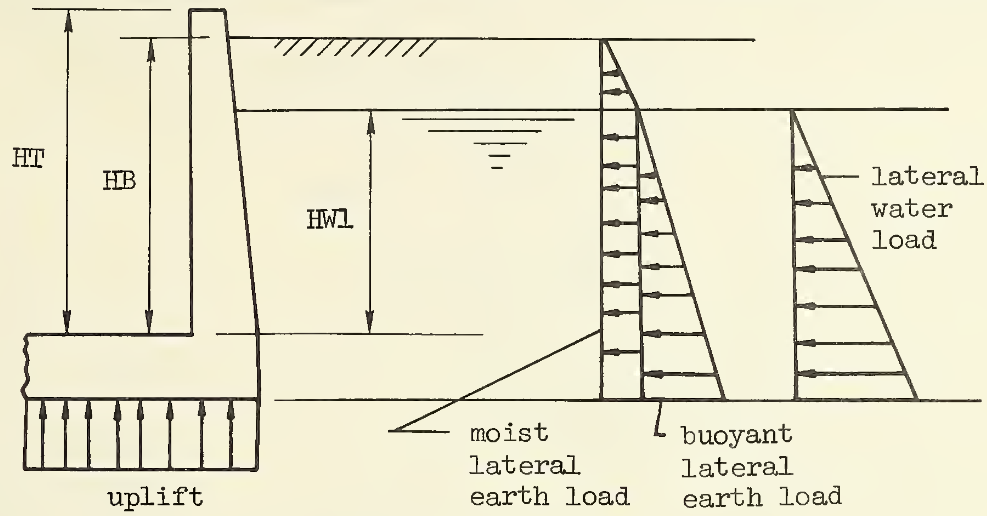


Figure 2. Load condition No. 1.

Load Condition No. 2

In this loading the channel is full of water to the top of the wall and the backfill is submerged to a height, HW2, above the top of the floor slab. Load condition No. 2 is meant to represent conditions following a rapid raising of the water surface in the channel, but before the water table in the backfill has raised significantly from a low level. Thus this loading should minimize lateral soil load, lateral external water load, and uplift. The lateral pressure ratio, KO2, should be taken as low as can reasonably be expected.

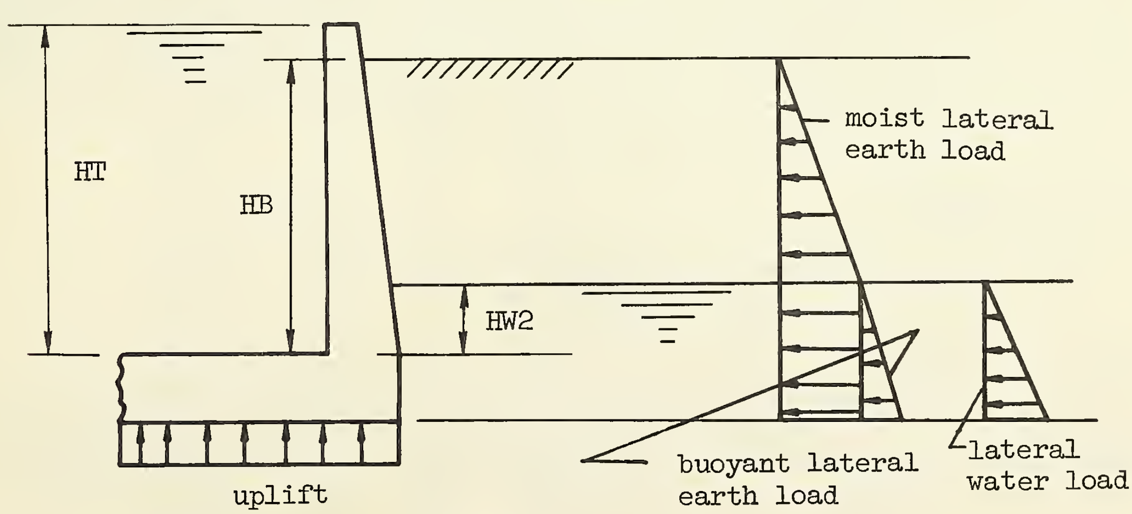


Figure 3. Load condition No. 2.

Flotation Requirement

The total weight of the structural channel plus all downward forces acting on it must exceed the uplift forces by a suitable safety factor under all conditions of loading. The most critical case is load condition No. 1. The flotation safety factor, FLOATR, is selected by the user. Footing projections, FTG, are added, when required, to develop necessary

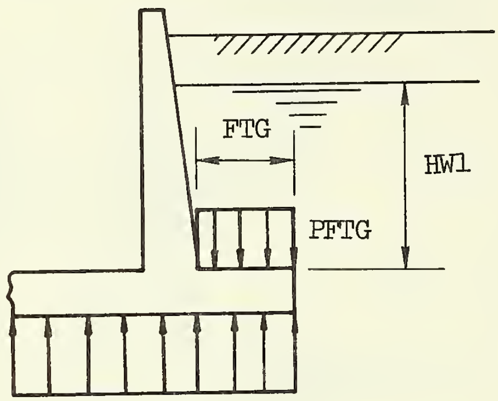


Figure 4. Flotation conditions.

additional downward forces.

Surcharge

Because of the wide variety of possible surcharge loads, surcharge is not included herein as a specific loading. The effects of surcharge can be duplicated to some extent by arbitrarily increasing lateral pressure ratios, unit soil weights, or backfill heights. Increasing unit soil weights or backfill heights should be done cautiously when the surcharge is applied only intermittantly.

Design Parameters

There are some seventeen independent design parameters involved in the design of the aforementioned structural channel types. The design parameters are classified as either primary parameters or secondary parameters. Values for primary parameters must be supplied by the user for each design run. Secondary parameters will be assigned default values if values are not supplied by the user. The methods of supplying parameter values are discussed under the section, "Computer Designs."

Primary Parameters

HT ≡ height of wall above top of floor slab, in ft
HB ≡ height of backfill above top of floor slab, in ft
B ≡ clear width of structural channel, in ft

Secondary Parameters

Not all secondary parameters are used by all channel types. The secondary parameters and their default values are listed in Table 1. Usage of these parameters is explained where first encountered. Those parameters having limited use are indicated.

Table 1. Secondary parameters and default values

Parameter	Default	Usage
HW1 ≡ submergence height above top of floor slab, load condition No. 1, in ft	0.8HB	
HW2 ≡ submergence height above top of floor slab, load condition No. 2, in ft	0.1HB	
HWP ≡ uplift head on pavement slab, load condition No. 1, in ft	HW1	T3F,T3FV
KO1 ≡ lateral earth pressure ratio, load condition No. 1	0.8	
KO2 ≡ lateral earth pressure ratio, load condition No. 2	0.2	
KPASS ≡ passive earth pressure ratio	1/KO1	T3F
GMOIST ≡ moist unit weight of backfill, in pcf	120	
GSAT ≡ saturated unit weight of backfill, in pcf	140	
FLOATR ≡ safety factor against flotation	1.5	
MAXFTG ≡ maximum acceptable footing projection, in ft	0.5B	
JOINTS ≡ longitudinal span between transverse joints, in ft	*	T1S
CFSC ≡ coefficient of friction, soil to concrete	0.35	T3F
CFSS ≡ coefficient of friction, soil to soil	0.55	T3F
MFOUND ≡ modulus of the foundation, in pcf	100,000	T1F,T1S T3FV

*when $B \leq 10$: JOINTS = 20

$10 < B < 20$: JOINTS = 2B

$B \geq 20$: JOINTS = 40

Design Criteria

Materials
Class 4000 concrete and intermediate grade steel are assumed.

Working Stress Design
Design of sections is in accordance with working stress methods. The allowable stresses in psi are

Extreme fiber stress in flexure	$f_c = 1600$
Shear, V/bD*	$v = 70$
Flexural Bond	
tension top bars	$u = 3.4\sqrt{f_c'}/D$
other tension bars	$u = 4.8\sqrt{f_c'}/D$
Steel	
in tension	$f_s = 20{,}000$
in compression, axially loaded columns	$f_s = 16{,}000$

Minimum Slab Thicknesses

Walls	10 inches
Bottom slabs	11 inches

Temperature and Shrinkage Steel
The minimum steel ratios are

for unexposed faces	$p_t = 0.001$
for exposed faces	$p_t = 0.002$

Slabs more than 32 inches thick are taken as 32 inches.

Web Reinforcement
The necessity of providing some type of stirrup or tie in the slabs because of bending action is avoided by

(1) limiting the shear stress, as a measure of diagonal tension, so that web steel is not required, and

(2) providing sufficient effective depth of sections so that compression steel is not required for bending.

Cover for Reinforcement
Steel cover is everywhere 2 inches except for outside steel in bottom slabs where cover is 3 inches.

Steel Required by Combined Bending Moment and Direct Force
Required area determined as explained on pages 31 - 34 of TR-42, "Single Cell Rectangular Conduits - Criteria and Procedures for Structural Design."

Spacing Required by Flexural Bond
Spacing determined as explained on page 47 of TR-42.

Spacing of Reinforcement
The maximum permissible spacing of any reinforcement is 18 inches.

*Shear sometimes critical at D from face, sometimes at face, see page 17 of TR-42.

Preliminary Designs

Trial concrete thicknesses are determined for various critical dimensions and preliminary concrete volumes are computed during the preliminary design phase of structural channel design. These quantities may be increased during detail design if computations for required steel areas and spacings indicate thicknesses are inadequate. Assumptions, criteria, and procedures for the several channel types are discussed below. Topics applicable to more than one channel type are presented once when first encountered.

Type T1F

Preliminary design of type T1F channels proceeds in an orderly manner. First, required wall thickness at the bottom of the wall, TB, is determined. Then, the channel is checked for flotation and footing projections, FTG, are provided if required. Finally, the floor slab thickness is increased for shear if necessary.

Wall thicknesses. The wall thickness at the top of the wall, TT, is set at 10 inches. The thickness at the bottom of the wall, TB, is selected as the largest thickness required by: shear for load condition No. 1 (LC#1), by moment and direct force for LC#1, by shear for LC#2, or by moment and direct force for LC#2. Illustrative computations for a possible case of LC#1 follow.

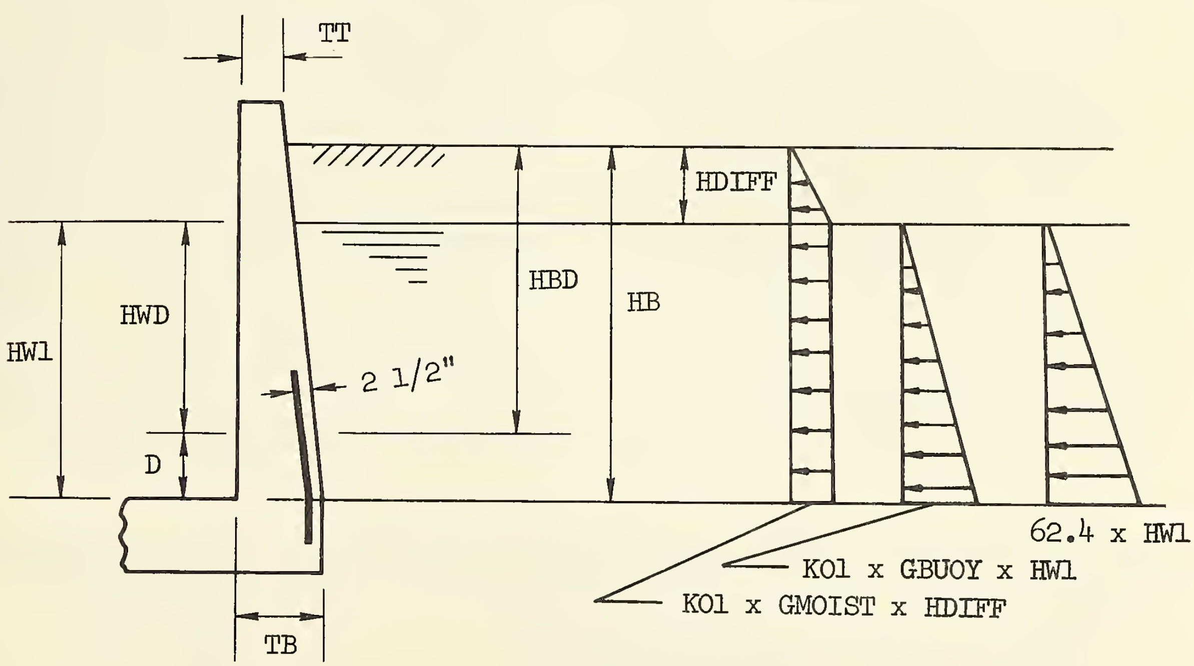


Figure 5. Thickness TB for LC#1 when HB > HW1.

Let HDIFF = HB - HW1
For any effective depth, D, in inches, let

$$HWD = HW1 - D/12$$
$$HBD = HB - D/12$$

Then the shear, in lbs per ft, at D from face for case shown is:

$$V = 31.2 \times (HWD)^2 + KO1 \times GMOIST \times HDIFF \times (0.5 \times HDIFF + HWD) + 0.5 \times KO1 \times GBUOY \times (HWD)^2$$

where GBUOY = GSAT - 62.4 is the buoyant weight of the backfill, in pcf

So $$D = \frac{V}{vb} = \frac{V}{70 \times 12} = \frac{V}{840}$$

An iterative process is required since the assumed D must agree with the computed required D. When the correct value of D is obtained, the thickness, T, at D from the face is

$$T = D + 2.5$$

and the thickness, TB, as required by shear is

$$TB = 10 + (T - 10) \times HT/(HT - D/12).$$

The bending moment at the bottom of the wall is, in ft lbs per ft

$$M = 10.4 \times (HW1)^3 + 0.5 \times KO1 \times GMOIST \times (HDIFF)^2 \times (HDIFF/3 + HW1) + 0.5 \times KO1 \times GMOIST \times HDIFF \times (HW1)^2 + 0.5 \times KO1 \times GBUOY \times (HW1)^3/3$$

The direct compressive force due to the wall, in lbs per ft, for a bottom thickness, TB, is

$$N = 6.25 \times HT \times (TT + TB)$$

The equivalent moment, M_s, is

$$M_s = M + N \times (0.5 \times TB - 2.5)/12$$

So the required bottom thickness for balanced working stress conditions is

$$TB = (0.003683 \times M_s)^{1/2} + 2.5$$

An iterative process is again required since the assumed TB must agree with the computed required TB.

Computations are similar for LC#2. The largest required thickness controls.

Flotation. As previously noted, LC#1 is critical with regard to flotation. For the case shown in Figure 6, the pressure, in psf, on the footing projections is

$$PFTG = GMOIST \times HDIFF + GSAT \times HW1$$

the uplift pressure, in psf, for a floor slab thickness, TS, in inches, is

$$PUP = 62.4 \times (HW1 + TS/12)$$

the overall width of the channel, in ft, is

$$WO = B + 2(FTG + TB/12)$$

Hence the ratio, R, of the downward forces on the channel to the uplift force is

$$R = \frac{2(N + PFTG \times FTG) + 12.5 \times TS \times WO}{PUP \times WO}$$

where $N = 6.25 \times HT \times (TT + TB)$.
This ratio must not be less than the flotation safety factor, FLOATR.

The initial value of TS is TS = TB + 1 and the initial value of FTG is zero. If R < FLOATR, then FTG is set at 1.0, if again R < FLOATR, then FTG is incremented by 0.2 ft and another attempt is made. This process is continued, if necessary, until FTG = MAXFTG, then TS is incremented by 1.0 inch until TS = TB + 10. If the flotation criteria is still unsatisfied, the design is abandoned, and a cancellation message is given.

<u>Floor slab shear</u>. Shear will sometimes govern the required thickness of the floor slab. For load condition No. 1 the compressive wall forces and the pressure on the footing projections are the only loads producing shear in the floor slab. The uniform loading, in psf, causing shear is

$$PS = 2(N + PFTG \times FTG)/WO$$

The required floor slab thickness due to shear is obtained from an expression for shear stress at D from the face of the wall, or using 3.5 inches as distance to center of steel

$$TS = (0.5 \times PS \times B)/(840 + PS/12) + 3.5$$

Occasionally LC#2 may be more critical than LC#1. The same expression may be used to obtain a required TS, however PFTG and PS must be recomputed for LC#2 with PS taking account of the floor pressures due to the water in the channel. Thus

$$PS = 62.4 \times HT - (62.4 \times HT \times B + 2(N + PFTG \times FTG))/WO.$$

If PS $\leq$ 0, no further computations for TS are necessary since LC#1 is the more critical.

Note that in the above expression for TS, from a theoretical viewpoint, 2.5 could sometimes be used instead of 3.5. To avoid confusion, 3.5 is always used to get these values of required TS for shear.

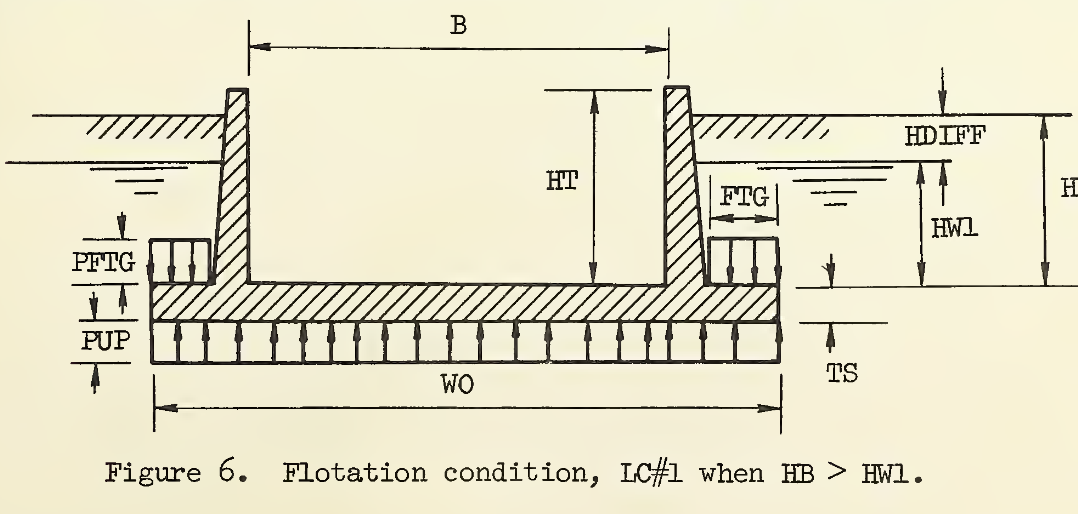


Figure 6. Flotation condition, LC#1 when HB > HWl.

Type T3F

The preliminary design of type T3F channels includes the design of many trial configurations. The toe length, X, varies from B/2 to 0. The design having the least concrete volume is taken as best. Determination of TT and TB is the same as type T1F. For a particular value of X, the flotation requirements for the retaining wall portion is the same as type T1F, that is, if B is temporarily taken as B = 2X, the same relations apply. This provides an initial value for FTG. In type T3F designs, FTG is the heel length of the retaining wall base.

Base design. The maximum allowable bearing pressure, that is, contact or intergranular pressure, is taken as 2000 psf in excess of the intergranular pressure that would exist at the elevation of the bottom of the base slab if the structural channel were not present. The line of action of the reaction (sum of all vertical forces including uplift) must lie within the middle third of the base. Each design for a particular X must satisfy the above criteria. If this requirement is not satisfied with the initial value of FTG, the footing projection is incremented and another trial is made. This is repeated, if necessary, up to FTG = MAXFTG.

A possible case of LC#1 is used for illustration. Let, in ft

$$\begin{aligned} HDIFF &= HB - HW1 \\ HS &= HB + TS/12 \\ HW &= HW1 + TS/12 \\ W &= X + TB/12 + FTG \end{aligned}$$

Then, in psf

$$\begin{aligned} PFTG &= GMOIST \times HDIFF + GSAT \times HW1 \\ PALLOW &= 2000 + GMOIST \times HDIFF + GBUOY \times HW \\ PUP &= 62.4 \times HW \end{aligned}$$

The sum of the vertical forces in lbs per ft, is

$$VNET = N + PFTG \times FTG + (12.5 \times TS - PUP) \times W$$

The overturning moment, in ft lbs per ft, about 0 at the bottom of the toe is

$$\begin{aligned} M_o = 10.4(HW)^3 &+ 0.5 \times KO1 \times GMOIST \times (HDIFF)^2 \times (HDIFF/3 + HW) \\ &+ 0.5 \times KO1 \times GMOIST \times HDIFF \times (HW)^2 \\ &+ 0.5 \times KO1 \times GBUOY \times (HW)^3/3. \end{aligned}$$

The resisting moment about the same moment center is

$$\begin{aligned} M_r = N \times (X + (TT + TB)/48) &+ PFTG \times FTG \times (W - 0.5 \times FTG) \\ &+ (12.5 \times TS - PUP) \times W^2 \times 0.5 \end{aligned}$$

Thus the distance from the end of the toe to VNET, in ft, is

$$Z = (M_r - M_o)/VNET$$

If $Z < W/2$, the bearing pressure, P1 is maximum.
If $Z > W/2$, the bearing pressure, P2 is maximum.

Now, in ft, the eccentricity of VNET, is

$$E = W/2 - Z$$

If $|E| > W/6$, the shape of the pressure diagram is unacceptable. If

$$\frac{VNET}{W}(1 + 6 \times |E|/W) > PALLOW$$

the maximum bearing pressure is too high.

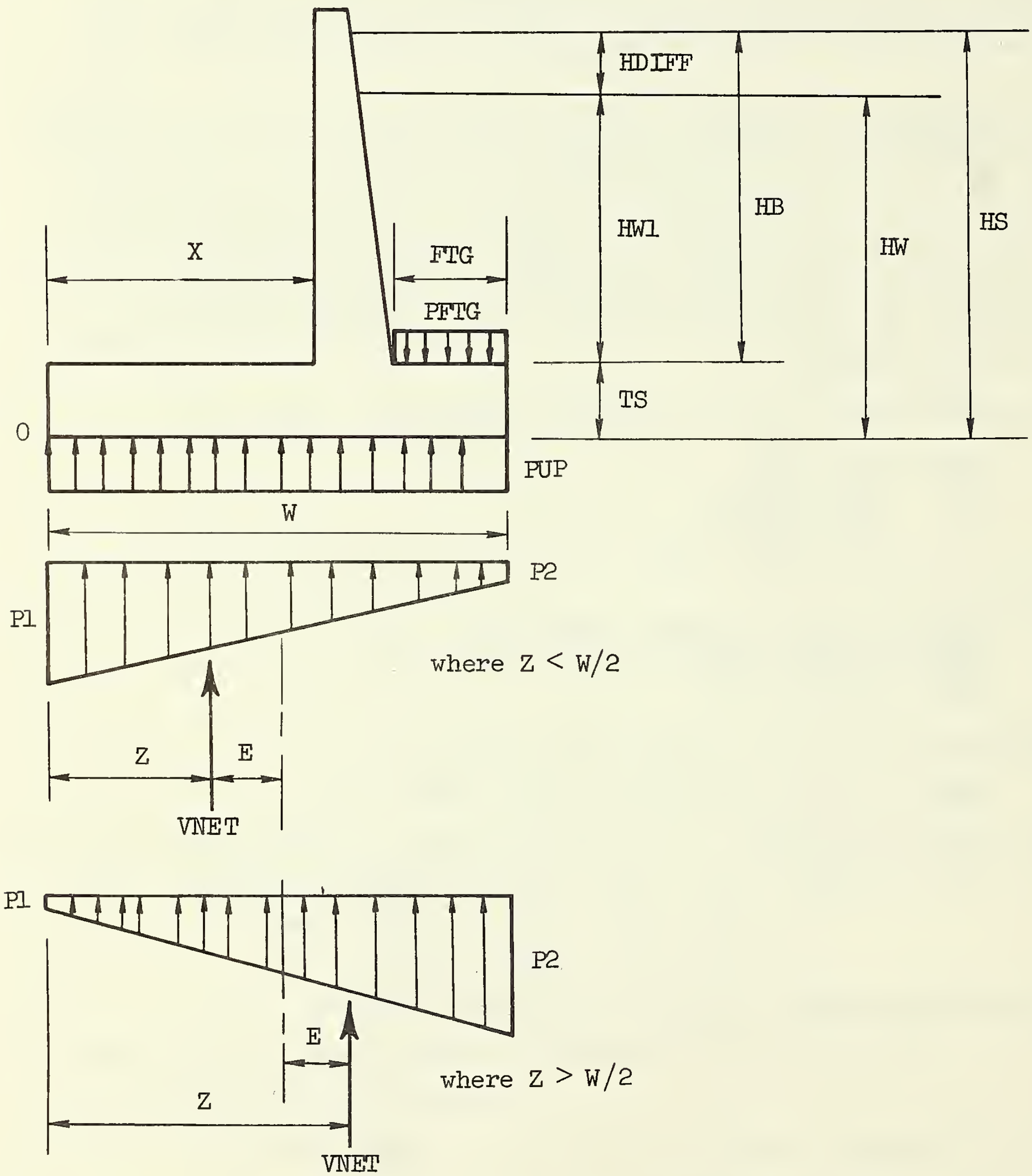


Figure 7. Bearing pressures, LC#1 when HB > HW1.

When bearing and pressure distribution requirements are satisfied, base thicknesses required for shear are determined. For LC#1, shear is investigated in the toe at distance D from the face of the support and in the heel at the face of the support. Several situations are possible in determining shear in the toe at D from the wall. Figure 8 illustrates one possibility in which $X > D$ and $Z < W/2$.

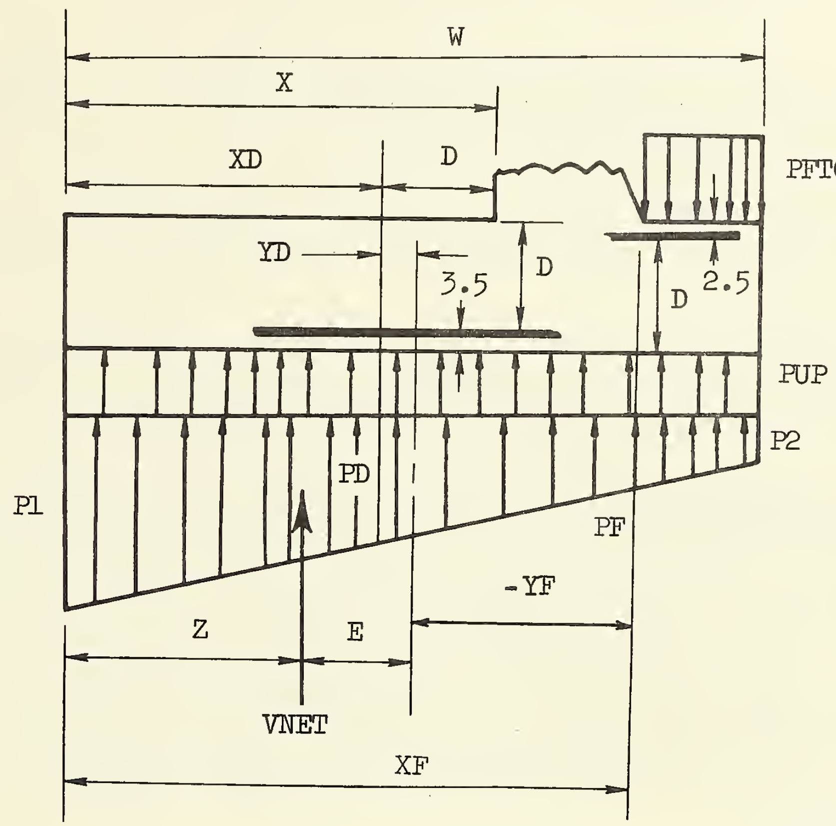


Figure 8. Investigation of footing shears.

Now

$$D = TS - 3.5$$
$$XD = X - D/12$$
$$YD = W/2 - XD$$

Then, in psf

$$P1 = \frac{VNET}{W}(1 + 6 \times E/W)$$

$$PD = \frac{VNET}{W}(1 + 12 \times E \times YD/(W \times W))$$

So the shear, in lbs per ft, at D from the face is

$$VD = (0.5(P1 + PD) + PUP - 12.5 \times TS) \times XD$$

To get the shear in the heel at the face of the support, let

$$XF = X + TB/12$$

then

$$YF = W/2 - XF$$

then

$$P2 = \frac{VNET}{W}(1 - 6 \times E/W)$$

and

$$PF = \frac{VNET}{W}(1 + 12 \times E \times YF/(W \times W))$$

So

$$VF = (PFTG + 12.5 \times TS - PUP - 0.5(P2 + PF)) \times FTG$$

The required thicknesses for these shears are

$$TS = VD/840 + 3.5$$

and

$$TS = VF/840 + 2.5$$

If either of these values exceeds the current TS, it is increased accordingly.

Computations are similar for LC#2. The water in the channel must be included in obtaining VNET and the resultant moments. Shears are investigated in the toe at the face of the support and in the heel at D from the face of the support.

Pavement slab thickness. In type T3F channels, the pavement slab is independent of the retaining wall portions of the channel. The pavement slab must therefore satisfy flotation requirements independently. The uplift head on the pavement slab is HWP. The uplift head could have been made a function of HW1, the same as for the retaining wall portions. However, it was felt that it should be possible to take account of drainage systems, etc. that might be built into the pavement. Note that HWP is measured from the bottom of the pavement slab, not from the top of the slab as is the case with HW1 and HW2. Thus the required thickness of the pavement slab to satisfy flotation requirements is, in inches,

$$TP = 62.4 \times HWP \times FLOATR/12.5$$

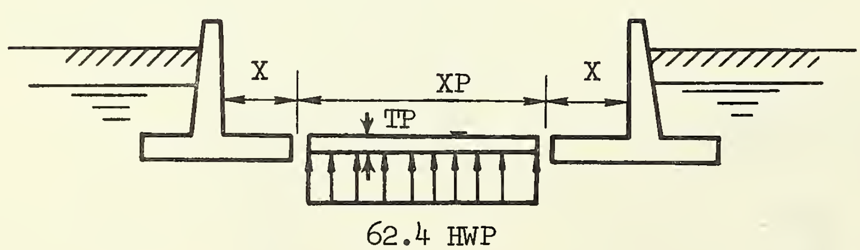


Figure 9. Pavement slab flotation, type T3F.

Type T3FV

The preliminary design of each type T3FV channel for a particular toe length, X, is similar to that for type T3F channels with one important exception. The joint between the pavement slab and the retaining wall base is designed to transmit shear from one structural component to the other. Thus the pavement slab and the retaining wall base are forced to deflect equally at the joint. Note that the joint is structurally a hinge, that is, it will transmit shears and direct forces, but not moments.

Determination of joint shear. An expression giving the shear transmitted through the joint may be obtained by equating expressions for the vertical displacement of the pavement slab, δ_p, at the joint and for the vertical displacement of the retaining wall base, δ_b, at the joint. It is assumed that such vertical displacements are equal to the intergranular bearing pressure (contact pressure) divided by the modulus of the foundation, that is

$$\delta = P/MFOUND$$

where

δ ≡ vertical displacement, in ft
P ≡ intergranular bearing pressure, in psf
MFOUND ≡ modulus of foundation, in pcf

Equating δ_p and δ_b, note that the term for the modulus of the foundation cancels out, and

$$P_b = P_p$$

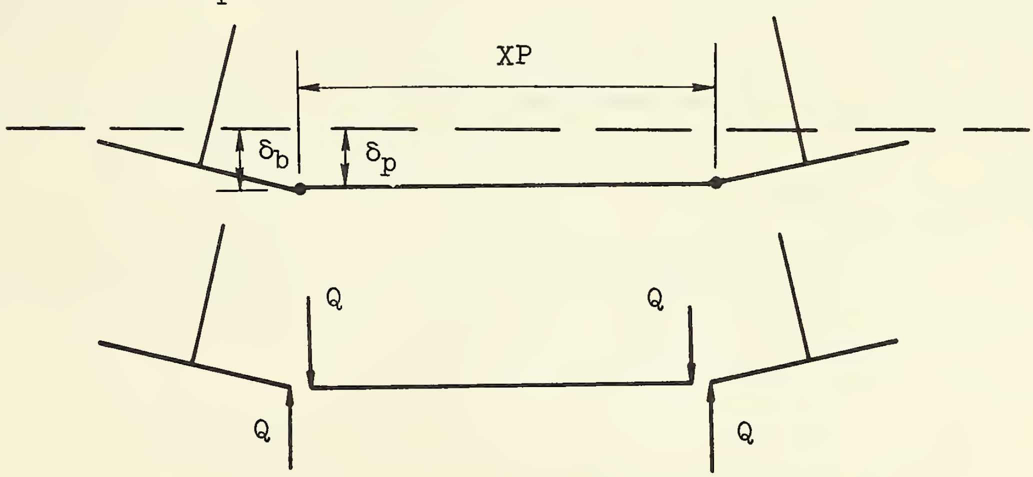


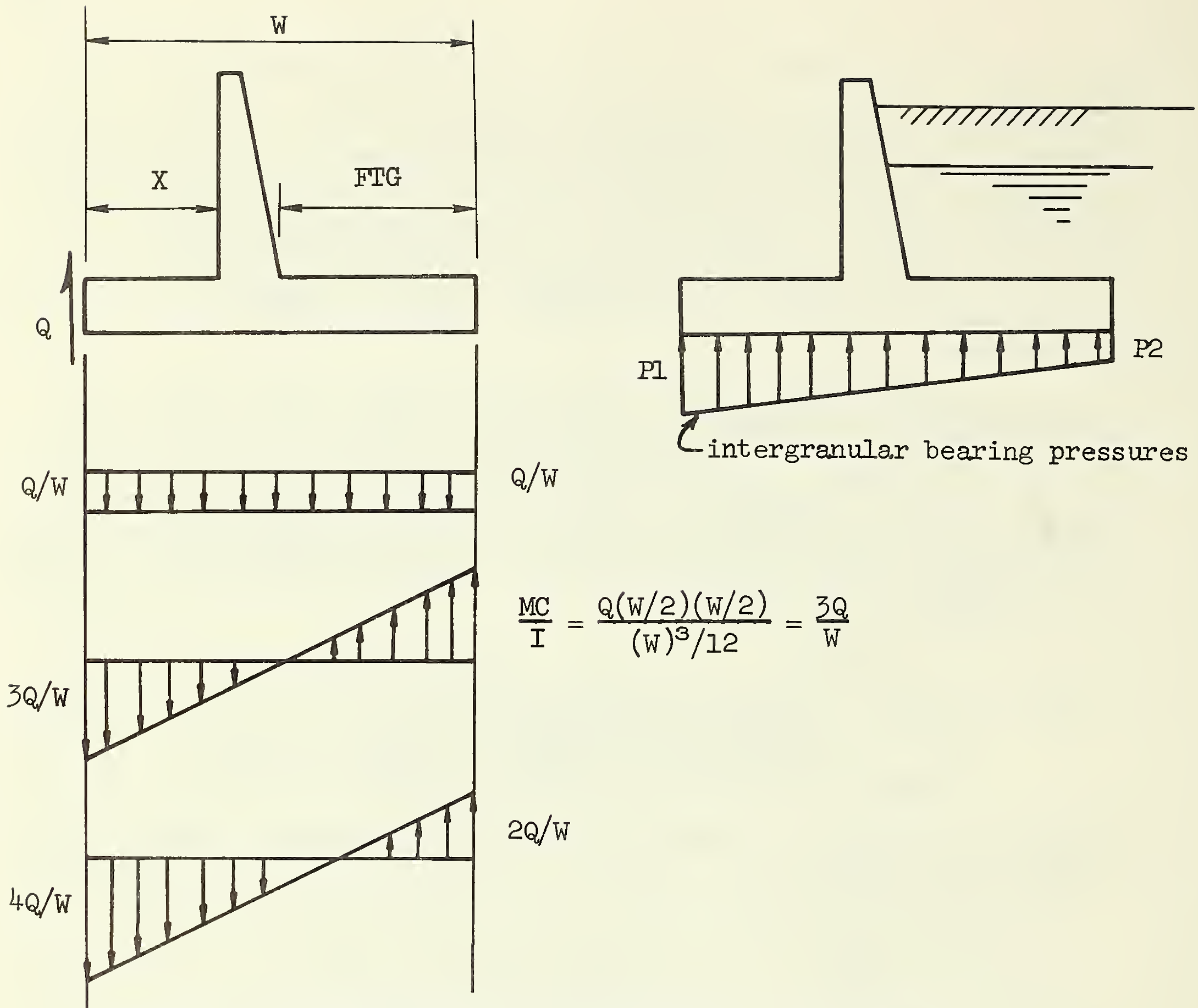
Figure 10. Joint shears in Type T3FV channels.

The pressure P_p, in psf, may be considered as that due to Q plus that due to any other loads on the pavement slab. If the pavement slab is treated as a "rigid body," the pressure due to Q is 2Q/XP. This leads to computed values of Q that are larger than actual values. If the pavement slab is treated as an "elastic body," the pressure due to Q is $Q\lambda$, where λ is given below. See "Floor Slab Analysis," pages 33 - 38 for development of similar theory and definition of terms.

$$\lambda = 2\beta\left(\frac{\cosh \beta\ell + \cos \beta\ell}{\sinh \beta\ell + \sin \beta\ell}\right), \text{ in per ft}$$

$$\beta = (5184 \times K/(E \times (TP)^3)^{1/4}, \text{ in per ft}$$

$$\beta\ell = \beta \times XP$$



$$\frac{MC}{I} = \frac{Q(W/2)(W/2)}{(W)^3/12} = \frac{3Q}{W}$$

Figure 11. Base pressures concerned with joint shears.

Thus

$$P_p = Q\lambda + WP$$

where WP ≡ pavement slab bearing pressure at shear joint, in psf.

Similarly, the pressure P_b may be thought of in two parts, that due to Q and that due to other loads. From Figure 11, noting that P1 may be obtained from relations described with type T3F

$$P_b = P1 - 4Q/W$$

Thus equating bearing pressures at the shear joint

$$Q\lambda + WP = P1 - 4Q/W$$

or, in lbs per ft

$$Q = (P1 - WP)\left(\frac{1}{\lambda + 4/W}\right)$$

This expression for Q may be thought of in two rather different ways. First, as presented, in which P1 and WP are independent of Q, so that the value of Q obtained from the expression is the true, total value of Q transmitted across the joint. Alternately, if P1 and WP are computed for loads which include an assumed value of Q, the value of Q obtained from the expression is the additional, or ΔQ required to produce equal vertical displacements. Both concepts are used in the design of type T3FV channels.

Design approach. Determination of TT and TB is the same as type T1F. For each value of X, the design cycles, starting with initial values of Q1 and Q2 (for LC#1 and LC#2) set equal to zero and continuing until the design stabilizes at constant values of FTG, TS, TP, Q1, and Q2. That is, for Q1 = Q2 = 0, the design obtains the required FTG, TS, and TP. Then new Q1 and Q2 are computed using the just determined dimensions, next new values of FTG, TS, and TP are obtained. Then new Q1 and Q2 values are computed, etc. The design usually quickly converges to correct values.

Wall base flotation. The wall base flotation is treated separately from pavement slab flotation, but each must account for Q1. Refering to Figure 6 and the flotation expressions under type T1F and letting B be taken temporarily as B = 2X, if Q1 acts upward on the wall base then

$$R = \frac{2 \times (N + PFTG \times FTG) + 12.5 \times TS \times WO}{PUP \times WO + 2 \times Q1}$$

if Q1 is negative, that is, acts downward on the wall base then

$$R = \frac{2 \times (N + PFTG \times FTG) + 12.5 \times TS \times WO - 2 \times Q1}{PUP \times WO}$$

R can not be less than FLOATR. Thus a minimum value of FTG corresponding to the current value of Q1 may be obtained.

Base design. Base design of type T3FV is the same as type T3F except that the appropriate shear, Q1 or Q2, must be included at the end of the toe. Thus for LC#1, the expression for the sum of the vertical loads is

$$VNET = N + PFTG \times FTG + (12.5 \times TS - PUP) \times W - Q1$$

Similarly, the expression for shear in the toe slab at D from the face of the support is

$$VD = (0.5(P1 + PD) + PUP - 12.5 \times TS) \times XD + Q1$$

Pavement slab thickness. In type T3FV channels, the thickness may be governed by flotation or by shear due to the joint shear.

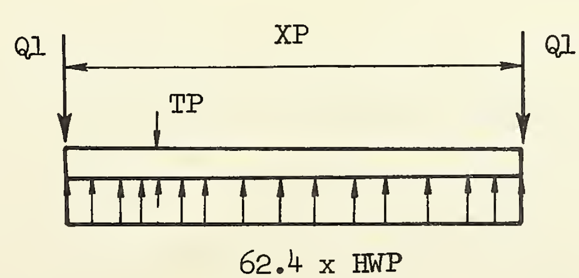


Figure 12. Pavement slab flotation, type T3FV.

If Q1 acts downward on the pavement slab, then required thickness for flotation is

$$TP = \frac{FLOATR \times 62.4 \times HWP \times XP - 2 \times Q1}{12.5 \times XP}$$

If, however, Q1 is negative, that is, acts upward on the pavement slab, then

$$TP = \frac{FLOATR \times (62.4 \times HWP \times XP - 2 \times Q1)}{12.5 \times XP}$$

Shear within the pavement slab is only caused by the transmitted joint shear, either LC#1 or LC#2 may control. LC#1 is used for illustration. Let

$$V = |Q1|$$

then, assuming a uniform loading due to Q1 of 2V/XP, the effective depth required is

$$DP = V/(840 + 2V/(12 \times XP))$$

If $Q1 > 0$, then

$$TP = DP + 2.5$$

If $Q1 < 0$, then

$$TP = DP + 3.5$$

The largest of the computed required thicknesses governs.

Delta Q. The computations indicated above, result in a new set of values for FTG, TS, and TP corresponding to a particular set of values of Q1 and Q2. The delta Q values are obtained as previously explained. For LC#1

$$\Delta Q1 = (P11 - WP1) \times \left(\frac{1}{\lambda + 4/W}\right)$$

where

$$WP1 = 12.5 \times TP - 62.4 \times HWP + Q1_{old}\lambda$$

P11 is P1 for LC#1 including effect of $Q1_{old}$

so

$$Q1_{new} = Q1_{old} + \Delta Q1$$

Similarly

$$\Delta Q2 = (P12 - WP2) \times \left(\frac{1}{\lambda + 4/W}\right)$$

where

$$WP2 = 12.5 \times TP + 62.4 \times HT - 62.4 \times (HW2 + TP/12) + Q2_{old}\lambda$$

P12 is P1 for LC#2 including effect of $Q2_{old}$

then if $(WP2 + 2 \times \Delta Q2/XP) > 0$

$$Q2_{new} = Q2_{old} + \Delta Q2$$

however, if $(WP2 + 2 \times \Delta Q2/XP) < 0$, then Q2 is limited to

$$Q2 = -(12.5 \times TP + 62.4 \times HT - 62.4 \times (HW2 + TP/12)) \times XP/2$$

These new Q1 and Q2 values are used in the next design cycle.

Type T1S

The design of type T1S channels is considerably more complex than any of the previous channel types presented. One of the problems involves the determination of the magnitude and distribution of the support provided the walls by the edge beams. Strut locations were selected at

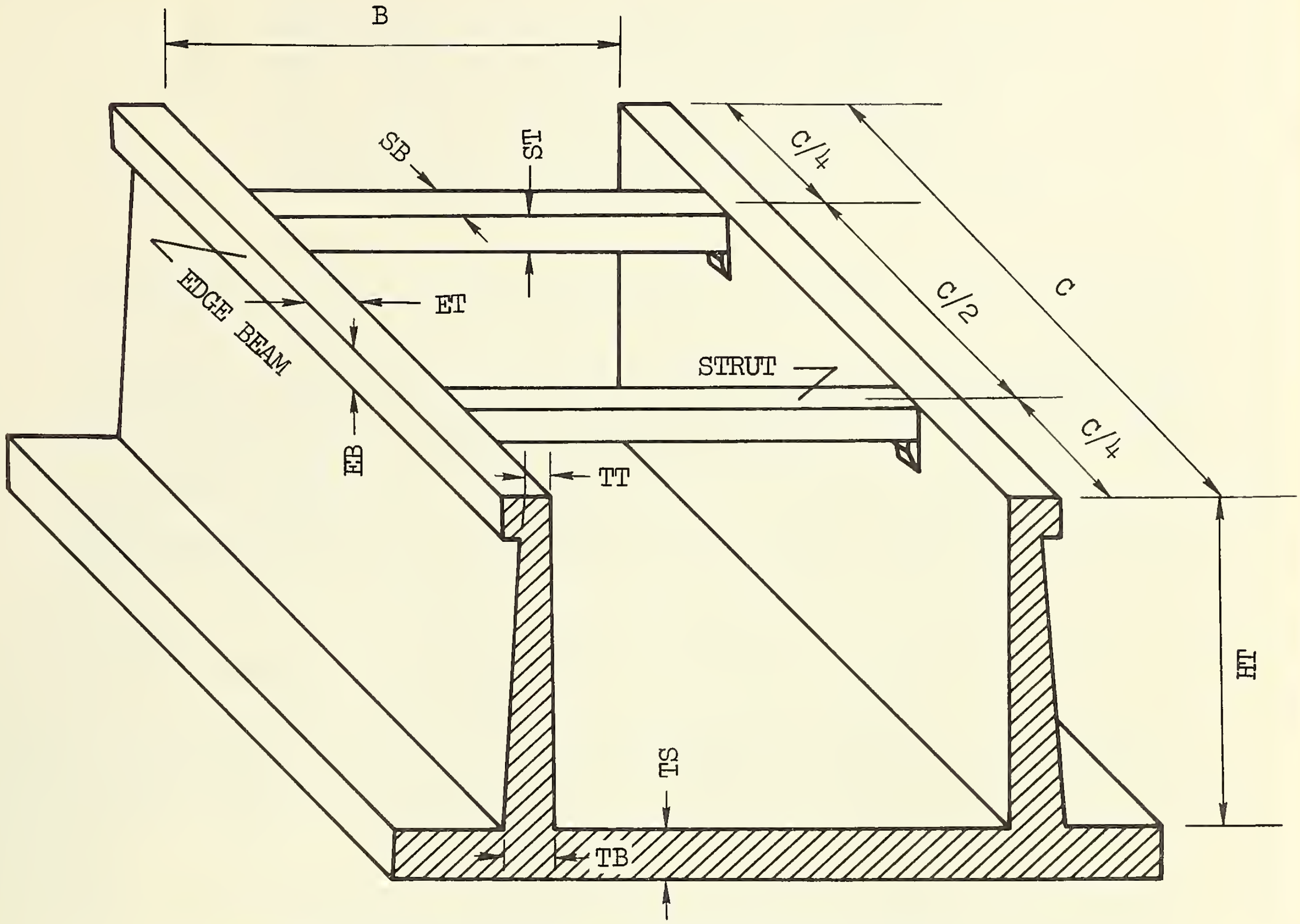


Figure 13. Definition sketch, type T1S channel.

the indicated quarter points of the longitudinal span between transverse channel joints for two reasons. The spacing is architecturally pleasing since the result is equally spaced struts in a long channel. Such spacing causes a considerable reduction in the maximum moments and shears that exist in the edge beams as compared to those that would exist if the struts were placed at the ends of the longitudinal spans. The struts require positive connections to the walls to prevent accidental dislodgement from the supporting wall brackets and because often the strut force will be direct tension rather than direct compression.

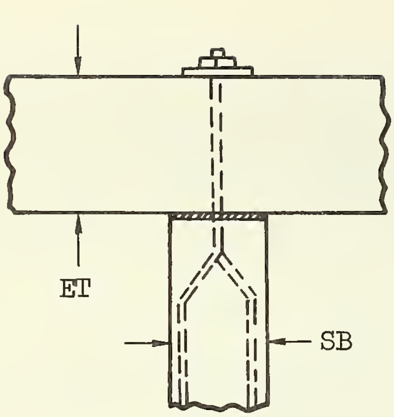


Figure 14. Possible strut-to-wall connections.

The wall bracket itself may be designed to prevent lateral movement of the struts.

Edge beam analyses. Before proceeding with the preliminary design, the edge beam theory is established. Load is brought to the edge beam by the vertical wall. The magnitude of this load, RX, varies from section to section along the wall. The struts provide the necessary edge beam reactions. The immediate problem is to describe and evaluate the loading on the edge beam. This may be accomplished by considering the frame

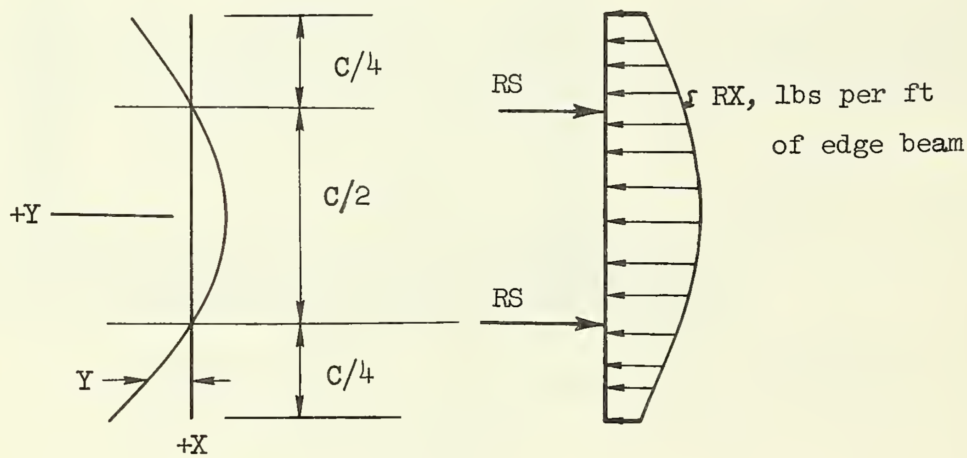


Figure 15. Edge beam loading and displacement.

displacements occuring at a typical vertical section in the channel.

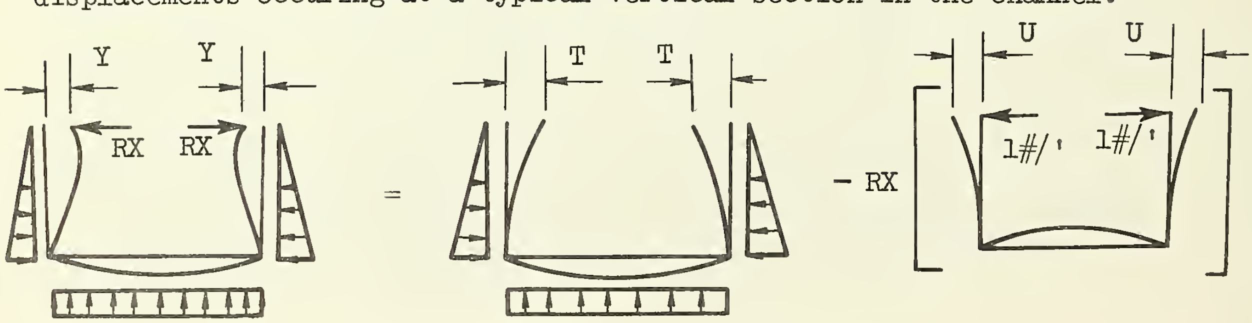


Figure 16. Type T1S frame displacements, typical loading.

The displacement at the top of the frame is $Y = T - U \times RX$
where

$Y \equiv$ displacement at top of frame, also displacement of the edge beam, in ft

$T \equiv$ displacement at top of frame with struts removed, in ft

$U \equiv$ displacement at top of frame due to unit horizontal loads at top of frame, in ft per lb per ft

$RX \equiv$ frame reaction provided by edge beam, also load on edge beam due to frame loading, in lbs per ft.

Thus

$$RX = T/U - Y/U$$

or

$$RX = m - nY$$

where

$$m = T/U \text{ and } n = 1/U$$

The frame constants, T, U, m, and n depend on the structural channel dimensions and loading. They are readily determined when needed.

The elastic curve equation for the edge beam is

$$EI\frac{d^4Y}{dX^4} = RX = m - nY$$

or letting

$$4\beta^4 = n/EI$$

then

$$\frac{d^4Y}{dX^4} + 4\beta^4 Y = m/EI$$

The general solution could be written and the constants of integration evaluated by applying various boundary conditions. This becomes rather involved and prone to error because of the interior location of the struts.

The above procedure can be avoided by utilizing a method of solution indicated on pages 15 - 17 of Timoshenko's "Strength of Materials, Part II," for the somewhat similar problem shown in Figure 17.

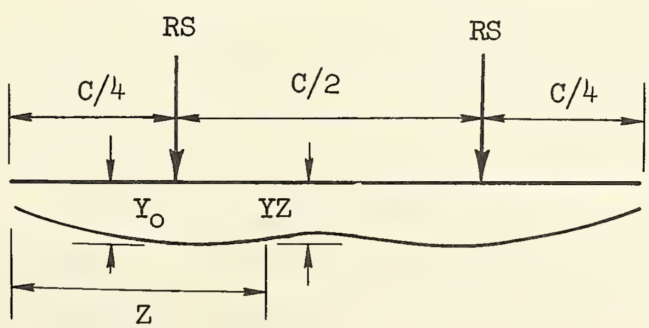


Figure 17. Alternate method of solution for edge beam analyses.

Let

$$\phi(\beta Z) = e^{-\beta Z}(\cos \beta Z + \sin \beta Z)$$
$$\psi(\beta Z) = e^{-\beta Z}(\cos \beta Z - \sin \beta Z)$$
$$\theta(\beta Z) = e^{-\beta Z} \cos \beta Z$$
$$\zeta(\beta Z) = e^{-\beta Z} \sin \beta Z$$

Then solve for Q_o and M_o from the simultaneous equations

$$\frac{Q_o}{4\beta}\left[1 + \psi(\beta C)\right] + \frac{M_o}{2}\left[1 + \theta(\beta C)\right] + \frac{RS}{4\beta}\left[\psi(3\beta C/4) + \psi(\beta C/4)\right] = 0$$
$$-\frac{Q_o}{2}\left[1 - \theta(\beta C)\right] - \frac{M_o\beta}{2}\left[1 - \phi(\beta C)\right] + \frac{RS}{2}\left[\theta(3\beta C/4) + \theta(\beta C/4)\right] = 0$$

Having Q_o and M_o, then for any Z, the deflection YZ, is

$$YZ = \frac{RS \times \beta}{2n}\left[\phi(\beta\{|C/4 - Z|\}) + \phi(\beta\{|3C/4 - Z|\})\right] + \frac{Q_o\beta}{2n}\left[\phi(\beta Z) + \phi(\beta\{C - Z\})\right] + \frac{M_o\beta^2}{n}\left[\zeta(\beta Z) + \zeta(\beta\{C - Z\})\right]$$

This expression finds the deflections due to symmetrical loads, RS, acting on a finite length beam. To convert to the edge beam problem note that $YX)_{X = C/4} = 0$, or let $YX = YZ - Y_o$
where

$$Y_o = \frac{RS \times \beta}{2n}\left[1 + \phi(\beta C/2)\right] + \frac{Q_o\beta}{2n}\left[\phi(\beta C/4) + \phi(3\beta C/4)\right] + \frac{M_o\beta^2}{n}\left[\zeta(\beta C/4) + \zeta(3\beta C/4)\right]$$

The sign of the deflections must also be changed to agree with the coordinate orientation shown in Figure 15.
Thus

$$YX = -(YZ - Y_o) = Y_o - YZ$$

The process of obtaining the magnitude and distribution of RX and of obtaining the magnitude of RS proceeds by trial as follows:

Let $RX_{aver} = m$, that is, assume $YX_{aver} = 0$

Then $RS = RX_{aver} \times C/2$

Evaluate YX, due to RS, at a large number of points
Compute new YX_{aver}, $RX_{aver} = m - nYX_{aver}$, and RS

Repeat this process until RS is essentially constant from one cycle to the next.
When constant RS is obtained, compute RX corresponding to each YX, that is,

$$RX = m - nYX$$

Design approach. As with most statically indeterminate systems, sizes and dimensions must be known or assumed before the system can be analyzed. Thus an initial set of trial dimensions is needed. Values for this initial set could simply be guessed, or some approximate methods could be used to obtain them. The latter is used herein. However, the approximations are not discussed separately here since what is more important is an understanding of a typical design cycle or iteration.

Design cycles are repeated as often as necessary to obtain a stable set of dimensions. Each cycle uses current forces to obtain new dimensions from which new forces are computed, etc., repeatedly. One design cycle is described below, assuming a set of trial dimensions is already available.

Edge beam loading. The first step in obtaining RX and RS values is to evaluate U and $n = 1/U$, in ft per lb/ft and lb/ft per ft respectively. These values depend solely on the dimensions of the frame. U is computed as

$$U = \frac{1}{2}\int_0^{\text{FRAME}} \frac{Myds}{EI} = \frac{1}{E}\sum^{\frac{1}{2}\text{FRAME}} \frac{My\Delta s}{I} = \frac{12}{E}\sum^{\frac{1}{2}\text{FRAME}} \frac{y^2\Delta s}{t^3}$$

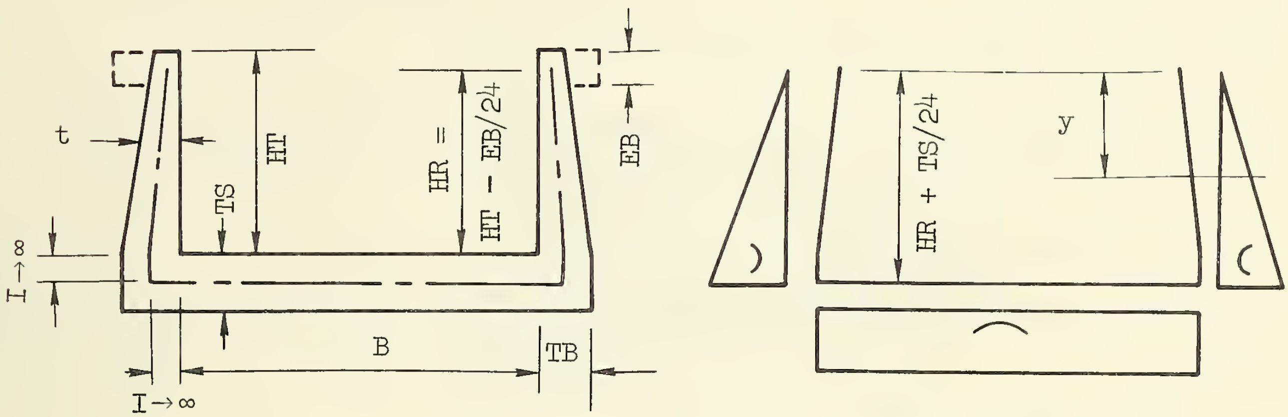


Figure 18. Evaluation of frame U and n.

where

- E ≡ modulus of elasticity of concrete, in psf
- y ≡ distance from mid-support of frame, in ft
- t ≡ thickness at y, in ft
- Δs ≡ incremental length along axis of frame, in ft

Next, T and $m = T/U$ in ft and lbs per ft are computed. T is computed as

$$T = \frac{1}{2}\int_0^{\text{FRAME}} \frac{Myds}{EI} = \frac{12}{E}\sum^{\frac{1}{2}\text{FRAME}} \frac{My\Delta s}{t^3}$$

where the terms are as previously defined and

M = average moment over the length Δs, in ft lbs per ft

LC#2 is used for illustration. LC#1 is similar, but without the effects

of water in the channel. Figure 19 indicates the vertical forces involved. The struts have been removed, but their effective weight is included in the force NWALL.

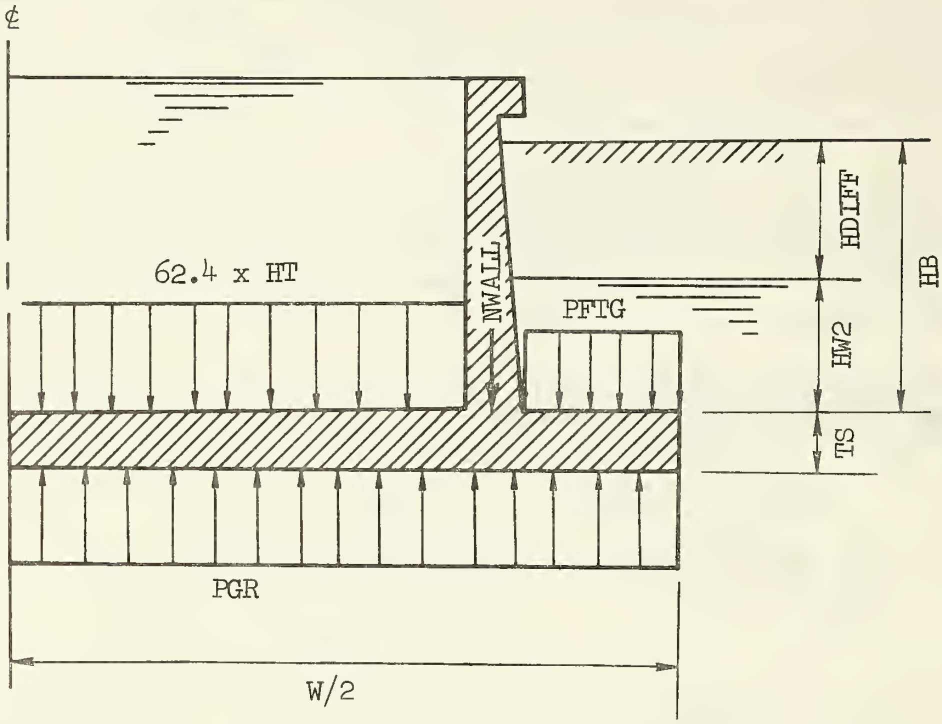


Figure 19. Vertical forces involved with frame T and m, LC#2 when HB > HW2.

This force, in lbs per ft, is

NWALL = 150 x B x ST x SB/(144 x C) + 150 x (ET - TT) x EB/144
+ 6.25 x HT x (TT + TB)

and here

PFTG = GMOIST x HDIFF + GSAT x HW2

so that PGR, which includes uplift, in psf, is

PGR = (2 x (NWALL + PFTG x FTG) + 12.5 x TS x W
+ 62.4 x HT x B)/W - 12.5 x TS

The summation for T over the wall portion of the frame is readily made. Wall moments due to external lateral loads produce a positive displacement, T, while wall moments due to internal water produce a negative displacement. The components of loads and moments involved in the summation for T over the floor portion of the frame are indicated in Figure 20. The summation may be said to include only the clear distance B/2 since I is assumed to approach infinity at the joints.

A concentrated moment is brought to the floor slab at the junction of wall stem and footing projection. This moment, MC, is the sum of two moments MWALL and MFTG. MWALL is the moment due to the loads acting on the wall stem. MFTG is due to the loads on the footing projection

and is

$$MFTG = 0.5 \times PGR \times (FTG + TB/24)^2 - PFTG \times FTG \times 0.5 \times (FTG + TB/12)$$

With reference to Figure 20, the summation for one half of the floor

$$T_f = (12/E) \times (MC - MR + 2 \times (MW - MB)/3) \times (HR + TS/24) \times 0.5 \times B/(TS/12)^3$$

where moments are in ft lbs per ft and other terms are as previously defined. Thus the frame displacement constants, m1 for LC#1, m2 for LC#2, and n are determined.

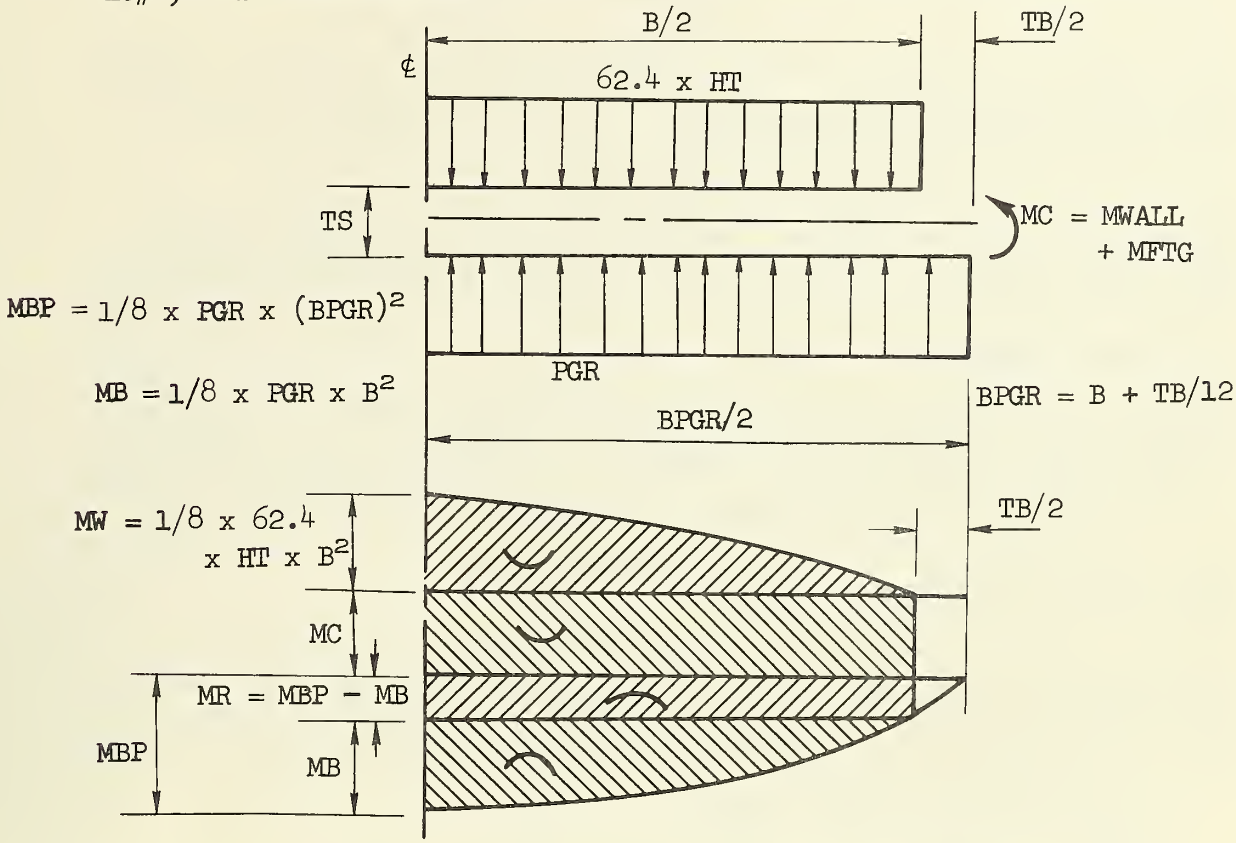


Figure 20. Floor slab loads and moments for frame T and m.

With the frame constants known, the edge beam loadings, RX, and the strut forces, RS, can be computed for LC#1 and LC#2 as outlined at the end of the section, "Edge beam analysis." In these computations the stiffness of the edge beam is reflected by the term β which is, per ft

$$\beta = \left(\frac{n}{4EI}\right)^{1/4} = 12\left(\frac{3n}{E \times EB \times (ET)^3}\right)^{1/4}$$

RX values are found for a large but finite number of points along the edge beam span. The signs of RX1 and RX2 are adjusted so that a positive RX has the meaning shown in Figure 21. It is possible to have values of RX1, RS1, RX2, and RS2 of either sense, that is, positive or negative.

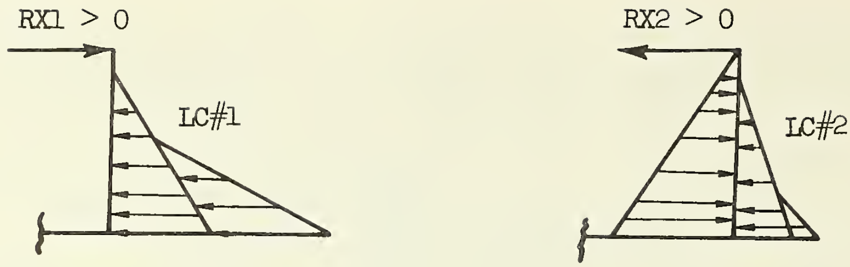


Figure 21. Sense of positive edge beam loading.

Strut design. With the edge beam loading known, the preliminary design can proceed with the determination of a new set of dimensions. The strut is the first unit re-evaluated.

The strut must be designed to carry direct tension if either strut reaction RS1 or RS2 is tensile. Let RT, in lbs, be the larger of any such tensile reaction. Then the required tension steel area, in sq inches, is

ATENS = RT/20,000

Minimum values for the strut dimensions, in inches, are

ST = B/20 for deflections control in accordance with ACI 909(b)

SB = B/50 for lateral support in accordance with ACI 908

Also, neither ST nor SB will be taken less than 12 inches, which more than satisfies ACI 912.

The strut must be capable of carrying the maximum compressive strut reaction, let this be RC, in lbs. In addition to RC, the strut carries its own dead weight in bending about the horizontal cross sectional axis of the strut. The process of compressive design is thus as follows.

Set SB & ST at minimum values.
Get dead load moment, in ft lbs:

MD = 0.125 x (150 x ST x SB/144) x B x B

Get eccentricity of RC due to MD, in inches

E = 12 x MD/RC

Get correction for long column by ACI Eq. (9-3)

RX = 1.07 - 0.008 x (12 x B)/(0.3 x ST) ≦ 1.0
= 1.07 - 0.32 x B/ST ≦ 1.0

Get direct compression for short column

NX = RC/RX

Take NX, see page 32 of TR-42, as larger of

NX or NX x 0.64 x (1.+ 4 x E/ST)

Take compressive steel area, ACOMP, in sq inches, as larger of

ATENS or 0.01 x ST x SB, in accordance with ACI 913(a)

Find required gross area of column, AGX in sq inches, from ACI Eq. (14-1) and ACI 1403

$$AGX = (NX - 13600 \times ACOMP)/850$$

Get correction for long columns

$$RY = 1.07 - 0.32 \times B/SB \leqq 1.0$$

Get direct compression for short columns

$$NY = RC/RY$$

Find required gross area of column

$$AGY = (NY - 13600 \times ACOMP)/850$$

Let AG = ST x SB in sq inches
If AGX, or AGY, or both, are greater than AG, then ST, or SB, or both are incremented accordingly and the cycle is repeated until both AGX and AGY are ≦ AG.

Edge beam design. The thickness of the edge beam is established by the requirements for bending moment. This is done on the assumption that web steel for diagonal tension will be provided when necessary. It should be noted that the edge beam is subjected to unknown amounts of torsion. Hence nominal closed stirrups (say #3 @ 12) should be provided even when diagonal tension web steel is not required. Thicknesses required for bending moment are determined at the centerline of the support since moments at midspan are small by construction. A summation

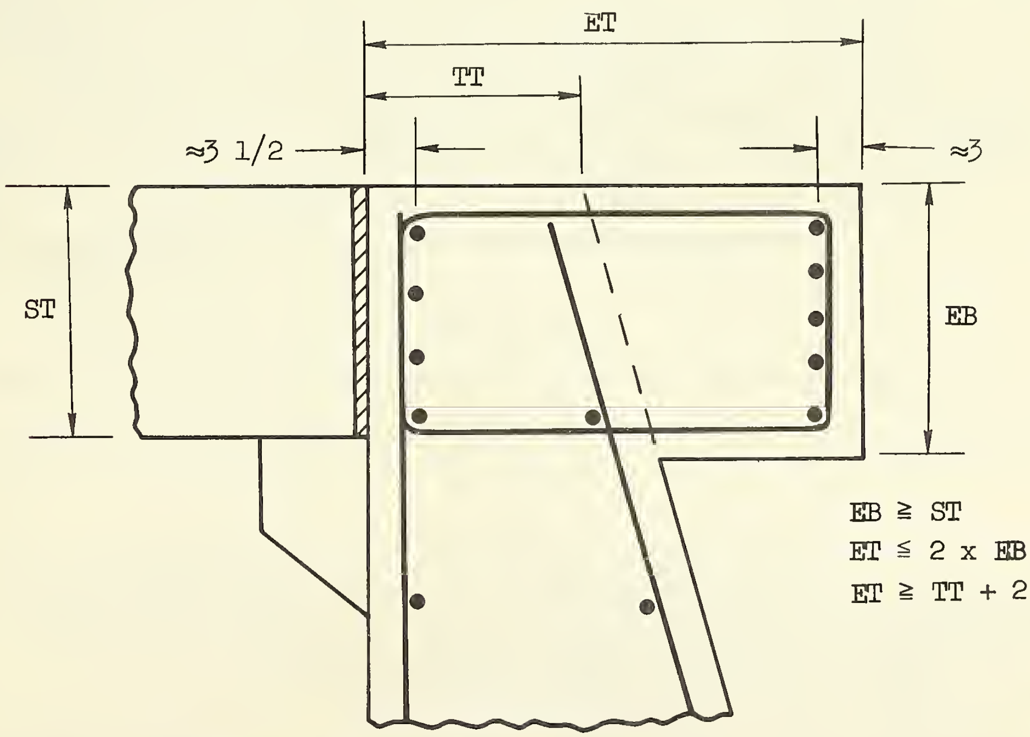


Figure 22. Edge beam section.

process is used to obtain the various shears and moments of interest because the loading curves assume various shapes.

Initially EB is set equal to ST. The maximum thickness required for bending is determined. If ET, so obtained, is more than twice EB, EB is incremented and another solution is made for ET. Next the maximum thickness which would be required for shear, assuming no web steel, is computed. If this thickness is more than that required for bending, web steel is required. Required web steel is calculated during detail design. Shears are investigated both left and right of the centerline of the support. When the strut reaction is compressive, shears are assumed critical at D from the faces of the support. When the strut reaction is tensile, shears immediately adjacent to the centerline are assumed critical.

Wall design. The wall must be designed for the most critical conditions that exist at any section along the wall between transverse channel joints. As noted, the edge beam provides a variable support to the wall. In order to control the most critical loadings on the wall during design, the maximum and minimum RX values are found for each load condition. These are RX1MAX, RX1MIN, RX2MAX, and RX2MIN respectively. Required wall thicknesses are found for shear at the top of the wall just below the edge beam, shear at the bottom of the wall, and moment at the bottom of the wall. Moment near midheight of the wall, of opposite sign to the moment at the bottom of the wall, often exists but is usually of smaller magnitude than the moment at the bottom.

Shear at top of wall, below edge beam. -- The maximum required thickness must be found for both load conditions. Shear is assumed critical at the face of the support, although an argument could be made for D from the support for LC#1 if RS1 > 0. LC#1 is used to illustrate one possible

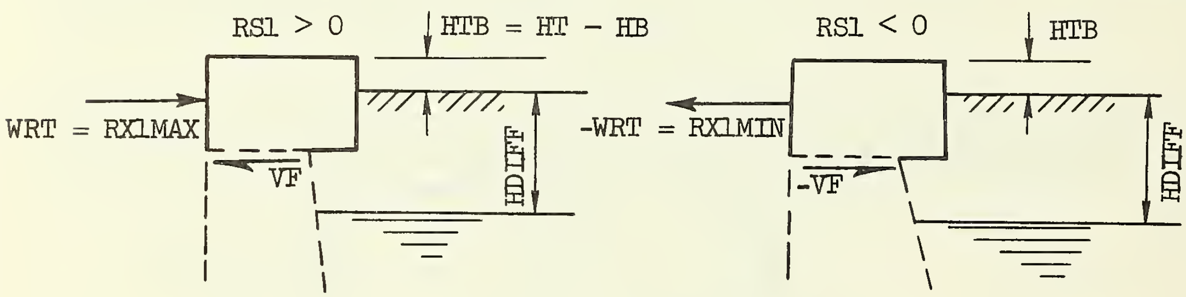


Figure 23. Shear at top of wall; LC#1 when HB > HW1, HTB < EB/12, and HW1 < HT - EB/12.

situation. For the situation shown, VF is the shear at the face, in lb lbs per ft

$$VF = WRT - 0.5 \times K01 \times GMOIST \times (EB/12 - HTB)^2$$

so, in inches

$$TT = (|VF|)/840 + 2.5$$

This is the thickness required at the face of the edge beam. Thus TT, projected to the top of the edge beam, could be taken somewhat smaller when TB > TT. This refinement is considered unwarrented since at this time the required TB is unknown.

Shear at bottom of wall. -- Shear is critical at D from the face of the support for LC#1 and at the face for LC#2. Since the shear at bottom of the wall is to be maximized, the wall reaction at the top, WRT, is set equal to the minimum edge beam loading. LC#1 is used for illustration.

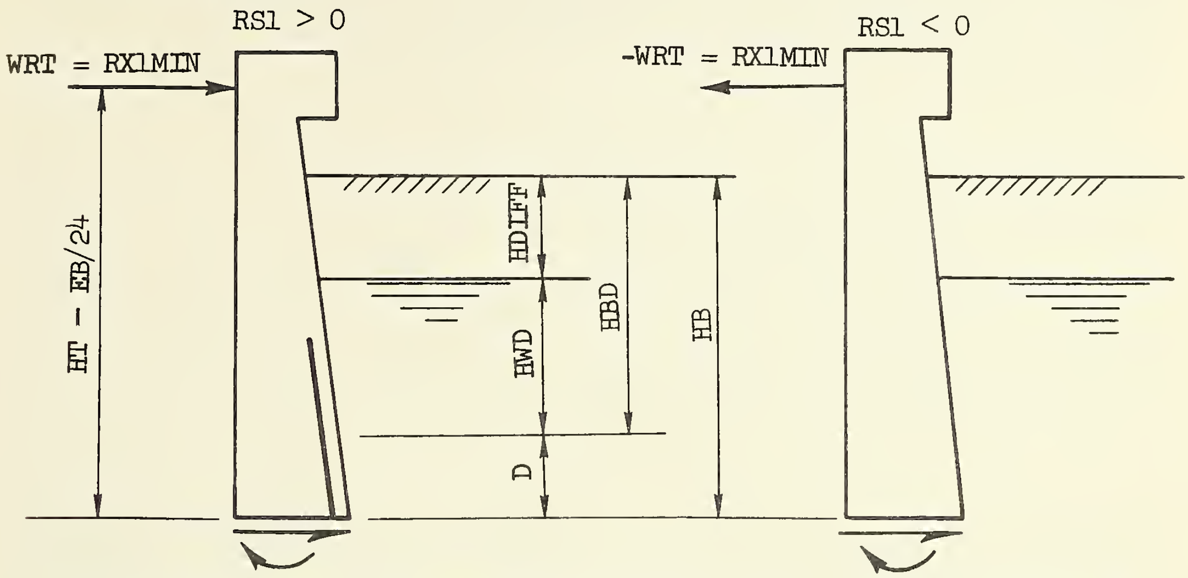


Figure 24. Shear and moment at bottom of wall, LC#1 when HB > HW1.

Computations and iterative process are similar to those explained for thickness TB for type T1F channels with the addition of WRT. The shear at D from the face is

$$V = 31.2 \times (HWD)^2 + K01 \times GMOIST \times HDIFF \times (0.5 \times HDIFF + HWD) + 0.5 \times K01 \times GBUOY \times (HWD)^2 - WRT$$

then

$$D = V/840$$

and, when computed and assumed D values agree

$$T = D + 2.5$$

so

$$TB = TT + (T - TT) \times HT/(HT - D/12)$$

Moment at bottom of wall. -- Moment at the bottom of the wall is maximized by using the smallest wall reaction at the top, hence Figure 24 applies.

The moment expression for LC#1 for the situation shown is the same as for type T1F with the addition of the WRT term, thus

$$\begin{aligned} M = 10.4 \times (HW1)^3 & + 0.5 \times K01 \times GMOIST \times (HDIFF)^2 \times (HDIFF/3 + HW1) \\ & + 0.5 \times K01 \times GMOIST \times HDIFF \times (HW1)^2 \\ & + 0.5 \times K01 \times GBUOY \times (HW1)^3/3 \\ & - WRT \times (HT - EB/24) \end{aligned}$$

The direct compressive force is NWALL as given under "Edge beam loading." The equivalent moment, M_s, thus is

$$M_s = M + NWALL \times (0.5 \times TB - 2.5)/12$$

The iterative process for TB then proceeds as explained for type T1F channels.

Flotation requirements and floor slab shear. Required footing projections, FTG, and required floor slab thickness, TS, are obtained as explained for type T1F channels with the substitution of NWALL for N to account for the weights of the struts and edge beams.

Detail Designs

With the exception of the steel in the edge beams of type T1S channels, detail design is concerned with the determination of requirements for transverse steel, not longitudinal steel.

Each detail design begins with the set of trial dimensions obtained in the preliminary design. Thicknesses are incremented, and the design recycled when necessary, whenever it is determined compression steel would otherwise be required to hold bending stresses to allowable working values. Required steel area and maximum allowable steel spacing are computed at a large number of points in the channel cross section. The points are similarly located and numbered in each structural channel type so that there is little difficulty in changing thought from one type to another. Schematic steel layouts are shown for each type. The actual steel layout is selected by the designer once he knows the steel requirements at the various points. The floor slab steel requirements for type T1F and T1S channels are based on analysis of the floor slab as a symmetrically loaded, finite length beam on an elastic foundation. This theory is presented before discussing the detail design of the four channel types.

Floor Slab Analysis

A means of determining the deflection, shear, and moment at any point, A, in the slab is required. This may be done by starting with the elastic curve equation

$$EI\frac{d^4Y}{dX^4} = P = -KY$$

or letting

$$4\beta^4 = K/EI$$

then

$$\frac{d^4Y}{dX^4} + 4\beta^4 Y = 0$$

where

K	≡ MFOUND =	modulus of foundation, in pcf
E	≡	modulus of elasticity of concrete, in psf
P	≡	foundation pressure, in psf
I	≡	moment of inertia, in ft^4 per ft
β	≡	$(5184 \times K/(E \times (TS)^3))^{1/4}$, in per ft
TS	≡	floor slab thickness, in inches

The modulus of the foundation, MFOUND, is also known by such names as: coefficient of subgrade reaction, subgrade modulus, coefficient of settlement, and modulus of subgrade reaction. Rather than work through the solution of the differential equation, it is easier to utilize various known solutions for infinite beams and to obtain the desired results by superposition. In Figure 25, solutions for (a) and (b) may be obtained by the procedure previously presented for the edge beam analysis. Loadings (c) and (d) require further development.

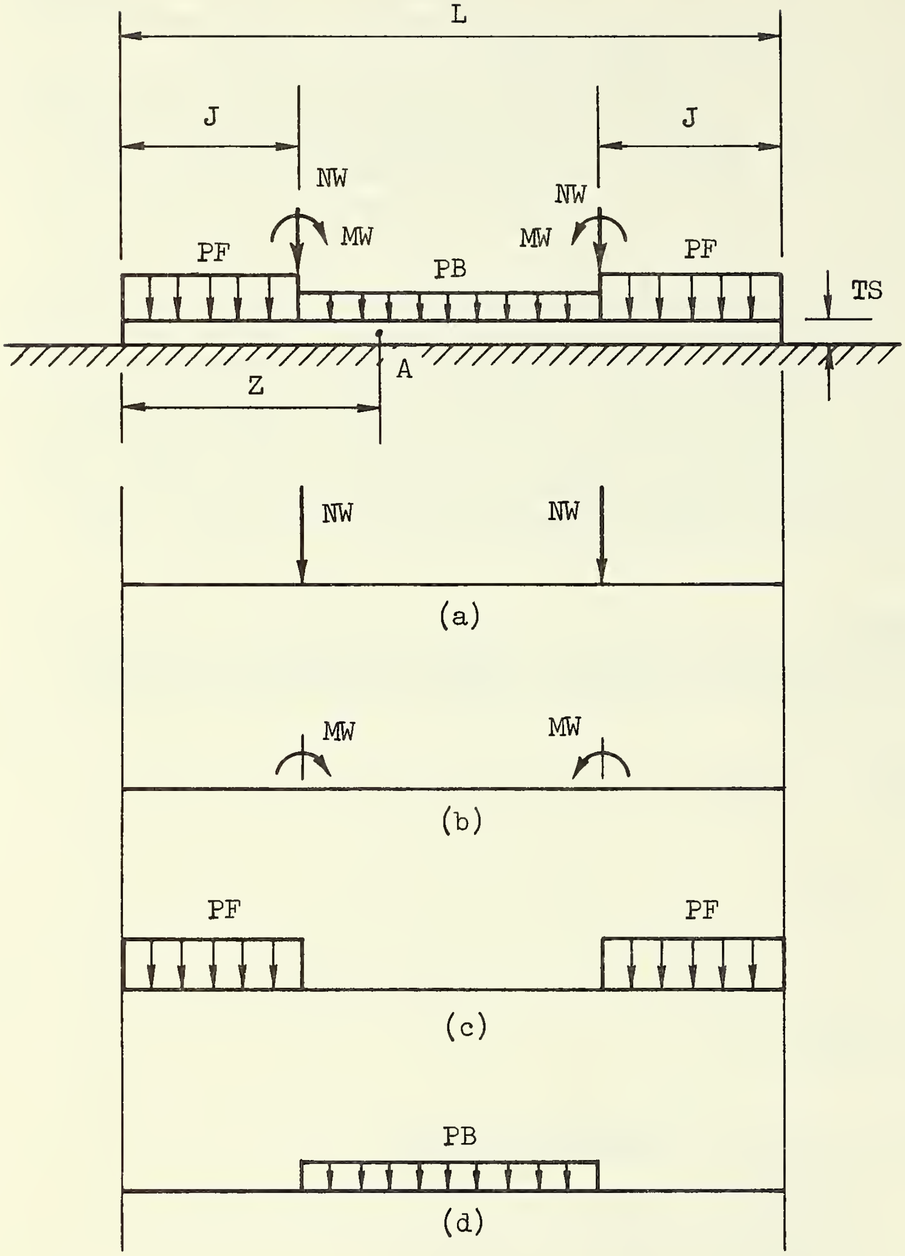


Figure 25. Finite length beam and loadings.

Deflection, shear, and moment due to NW. Expressions for deflection, shear, and moment are needed when the point A assumes various locations. Let YA, VA, and MA be these quantities in ft, lbs per ft, and ft lbs per ft respectively.

When A is at the left end of the beam, i.e. $Z = 0$

$$YA = \frac{NW \times \beta}{2K}\left[\phi(\beta J) + \phi(\beta\{L - J\})\right]$$

$$VA = \frac{NW}{2}\left[\theta(\beta J) + \theta(\beta\{L - J\})\right]$$

$$MA = \frac{NW}{4\beta}\left[\psi(\beta J) + \psi(\beta\{L - J\})\right]$$

When A is between the left end of the beam and the load, i.e., $0 \leqq Z \leqq J$

$$YA = \frac{NW \times \beta}{2K}\left[\phi(\beta\{J - Z\}) + \phi(\beta\{L - J - Z\})\right]$$

$$VA = \frac{NW}{2}\left[\theta(\beta\{J - Z\}) + \theta(\beta\{L - J - Z\})\right]$$

$$MA = \frac{NW}{4\beta}\left[\psi(\beta\{J - Z\}) + \psi(\beta\{L - J - Z\})\right]$$

When A is between the two loads, i.e., $J \leqq Z \leqq (L - J)$

$$YA = \frac{NW \times \beta}{2K}\left[\phi(\beta\{Z - J\}) + \phi(\beta\{L - J - Z\})\right]$$

$$VA = \frac{NW}{2}\left[- \theta(\beta\{Z - J\}) + \theta(\beta\{L - J - Z\})\right]$$

$$MA = \frac{NW}{4\beta}\left[\psi(\beta\{Z - Z\}) + \psi(\beta\{L - J - Z\})\right]$$

<u>Deflection, shear, and moment due to MW.</u> Expressions for deflection, shear, and moment due to the moment, MW, brought to the floor slab by the wall follow.

When $Z = 0$

$$YA = - \frac{MW \times \beta^2}{K}\left[\zeta(\beta J) - \zeta(\beta\{L - J\})\right]$$

$$VA = - \frac{MW \times \beta}{2}\left[\phi(\beta J) - \phi(\beta\{L - J\})\right]$$

$$MA = - \frac{MW}{2}\left[\theta(\beta J) - \theta(\beta\{L - J\})\right]$$

When $0 \leqq Z \leqq J$

$$YA = - \frac{MW \times \beta^2}{K}\left[\zeta(\beta\{J - Z\}) - \zeta(\beta\{L - J - Z\})\right]$$

$$VA = - \frac{MW \times \beta}{2}\left[\phi(\beta\{J - Z\}) - \phi(\beta\{L - J - Z\})\right]$$

$$MA = - \frac{MW}{2}\left[\theta(\beta\{J - Z\}) - \theta(\beta\{L - J - Z\})\right]$$

When $J \leqq Z \leqq (L - J)$

$$YA = \frac{MW \times \beta^2}{K}\left[\zeta(\beta\{Z - J\}) + \zeta(\beta\{L - J - Z\})\right]$$

$$VA = -\frac{MW \times \beta}{2}\left[\phi(\beta\{Z - J\}) - \phi(\beta\{L - J - Z\})\right]$$

$$MA = \frac{MW}{2}\left[\theta(\beta\{Z - J\}) + \theta(\beta\{L - J - Z\})\right]$$

<u>Deflection, shear, and moment due to uniform loading, q</u>. Before terms for the uniform loadings PB and PF can be obtained, solutions for uniform loads must be established. These are obtained by integrating the corresponding expressions for a concentrated load. Refer to Timoshenko, pages 6 and 7 for similar material.

Without proof:

$$\int\theta(\beta X)dX = -\frac{1}{2\beta}\,\psi(\beta X)$$

$$\int\zeta(\beta X)dX = -\frac{1}{2\beta}\,\phi(\beta X)$$

$$\int\phi(\beta X)dX = -\frac{1}{\beta}\,\theta(\beta X)$$

$$\int\psi(\beta X)dX = +\frac{1}{\beta}\,\zeta(\beta X)$$

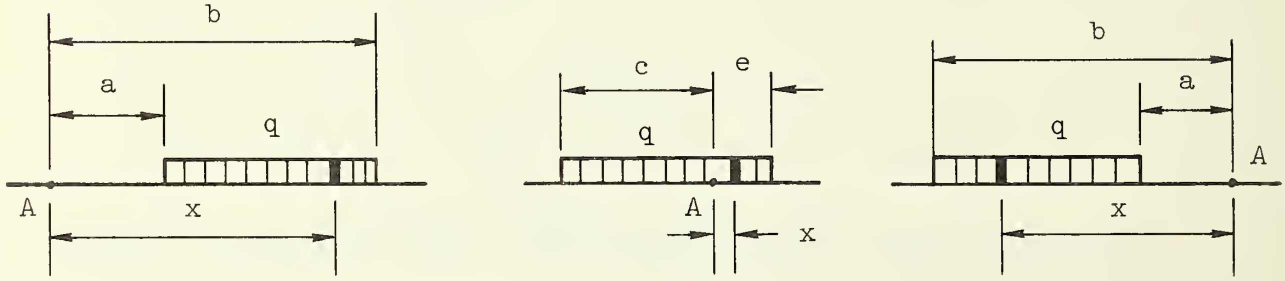


Figure 26. Uniform loading cases, infinite beams.

When A is to left of loading, noting that $dN = qdX$

$$YA = \int_0^b \frac{\beta q}{2K}\,\phi(\beta X)dX - \int_0^a \frac{\beta q}{2K}\,\phi(\beta X)dX = \frac{q}{2K}\left[\theta(\beta a) - \theta(\beta b)\right]$$

similarly

$$VA = \frac{q}{4\beta}\left[\psi(\beta a) - \psi(\beta b)\right]$$

$$MA = \frac{q}{4\beta^2}\left[-\zeta(\beta a) + \zeta(\beta b)\right]$$

When A is within the loading

$$YA = \int_0^e \frac{\beta q}{2K}\,\phi(\beta X)dX + \int_0^c \frac{\beta q}{2K}\,\phi(\beta X)dX = \frac{q}{2K}\left[2 - \theta(\beta C) - \theta(\beta e)\right]$$

and

$$VA = \frac{q}{4\beta}\left[\psi(\beta c) - \psi(\beta e)\right]$$

$$MA = \frac{q}{4\beta^2}\left[\zeta(\beta c) + \zeta(\beta e)\right]$$

When A is to be the right of loading

$$YA = \frac{q}{2K}\left[\theta(\beta a) - \theta(\beta b)\right]$$

$$VA = \frac{q}{4\beta}\left[- \psi(\beta a) + \psi(\beta b)\right]$$

$$MA = \frac{q}{4\beta^2}\left[- \zeta(\beta a) + \zeta(\beta b)\right]$$

Expressions for deflection, shear, and moment due to PB and PF can be found from the above terms upon correct substitution of PB, PF, L, J, and Z for q, a, b, c, and e.

Deflection, shear, and moment due to Q_o and M_o. The end shears and moments, Q_o and M_o, must be applied to the infinite beam in order to convert the problem to a finite length beam, these cause deflections, shears, and moments within the beam.

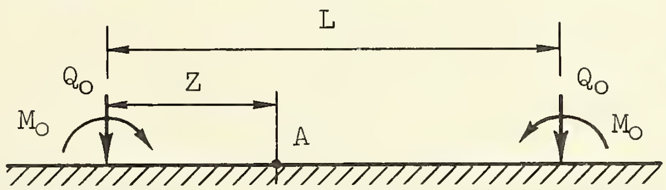


Figure 27. Q_o and M_o loadings, infinite beam.

When Z = 0

$$YA = \frac{Q_o\beta}{2K}\left[1 + \phi(\beta L)\right] + \frac{M_o\beta^2}{K}\zeta(\beta L)$$

$$VA = -\frac{Q_o}{2}\left[1 - \theta(\beta L)\right] - \frac{M_o\beta}{2}\left[1 - \phi(\beta L)\right]$$

$$MA = \frac{Q_o}{4\beta}\left[1 + \psi(\beta L)\right] + \frac{M_o}{2}\left[1 + \theta(\beta L)\right]$$

When $0 \leqq Z \leqq L$

$$YA = \frac{Q_o\beta}{2K}\left[\phi(\beta Z) + \phi(\beta\{L - Z\})\right] + \frac{M_o\beta^2}{K}\left[\zeta(\beta Z) + \zeta(\beta\{L - Z\})\right]$$

$$VA = \frac{-Q_o}{2}\left[\theta(\beta Z) - \theta(\beta\{L - Z\})\right] - \frac{M_o\beta}{2}\left[\phi(\beta Z) - \phi(\beta\{L - Z\})\right]$$

$$MA = \frac{Q_o}{4\beta}\left[\psi(\beta Z) + \psi(\beta\{L - Z\})\right] + \frac{M_o}{2}\left[\theta(\beta Z) + \theta(\beta\{L - Z\})\right]$$

Solution for Q_o and M_o. The required values for Q_o and M_o are computed from the simultaneous equations obtained by setting the sum of the shears and the sum of the moments at the end of the finite length beam, due to all loads, equal to zero. The necessary terms, for the various shears and moments, are given above.

Solution for finite beam. With Q_o and M_o known, expressions for the deflection, shear, and moment may be written for any point, A, in the beam. Different expressions will result depending on whether $0 \leqq Z \leqq J$ or $J \leqq Z \leqq (L - J)$. As one example, the expression for moment, in ft lbs per ft, at A when $Z > J$ is

$$\begin{aligned} MA = {} & \frac{Q_o}{4\beta}\Big[\psi(\beta Z) + \psi(\beta\{L - Z\})\Big] \\ & + \frac{M_o}{2}\Big[\theta(\beta Z) + \theta(\beta\{L - Z\})\Big] \\ & + \frac{NW}{4\beta}\Big[\psi(\beta\{Z - J\}) + \psi(\beta\{L - J - Z\})\Big] \\ & + \frac{MW}{2}\Big[\theta(\beta\{Z - J\}) + \theta(\beta\{L - J - Z\})\Big] \\ & + \frac{PB}{4\beta^2}\Big[\zeta(\beta\{Z - J\}) + \zeta(\beta\{L - J - Z\})\Big] \\ & + \frac{PF}{4\beta^2}\Big[-\zeta(\beta\{Z - J\}) + \zeta(\beta Z)\Big] \\ & + \frac{PF}{4\beta^2}\Big[-\zeta(\beta\{L - J - Z\}) + \zeta(\beta\{L - Z\})\Big] \end{aligned}$$

Note that a host of problems, in addition to the immediate one of channel floor slab, can be solved by this procedure, e.g., combined footings.

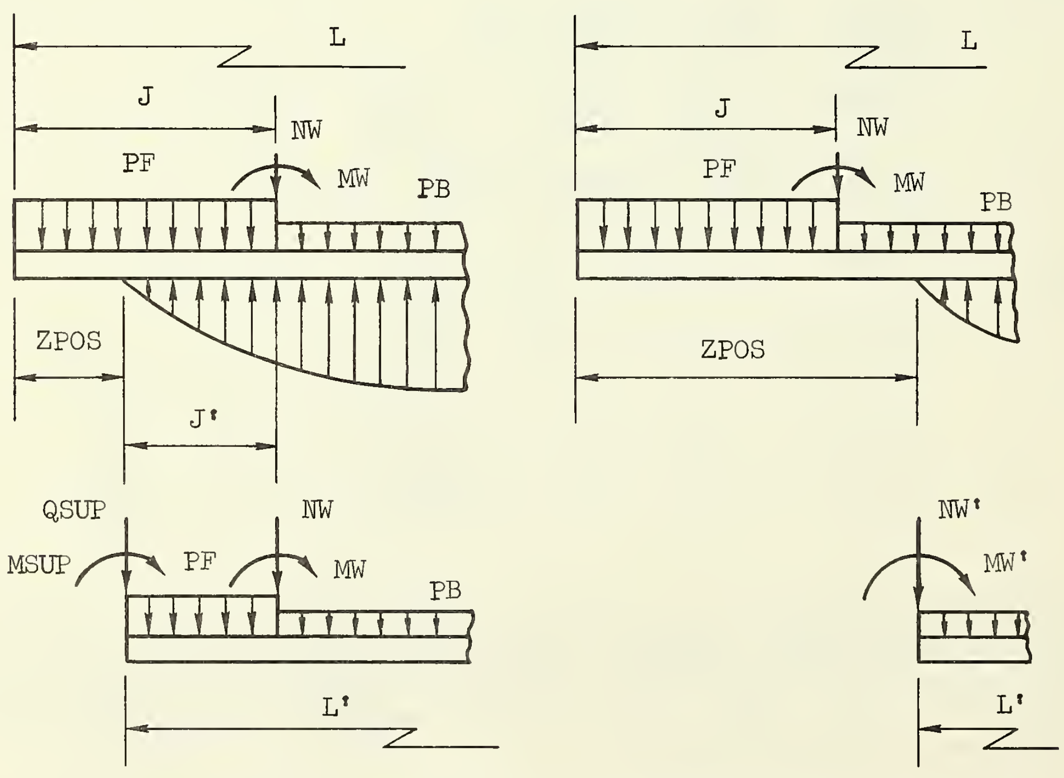


Figure 28. Corrections for indicated tensile reactions.

The solution is incorrect if negative deflections, indicating tensile reactive pressures, are encountered. This sometimes occurs at the ends of the beam. A correct solution is obtained by modifying the effective loading and dimensions of the finite length beam. Assume a solution is attempted, then let the distance from the end of the beam to the point of zero reactive pressure be ZPOS. If ZPOS = 0, the solution is correct. If $0 < \text{ZPOS} \leq J$, add the cantilever shear and moment, QSUP and MSUP, to the system. Change J to J', and L to L'. Solve this beam for a new ZPOS. If ZPOS > J, change NW to NW', MW to MW', J to 0.0, and L to L'. NW' and MW' are the statical cantilever equivalents of the forces and moments within the distance ZPOS. Solve this beam for a new ZPOS. The next solution will yield another ZPOS, etc. ZPOS values so found, will approach zero, that is, the series is convergent and may be stopped when desired.

Type T1F

Steel areas and spacings are determined for the twenty two points defined in Figure 29. Both LC#1 and LC#2 are investigated. Steel area for temperature and shrinkage is computed and will sometimes control.

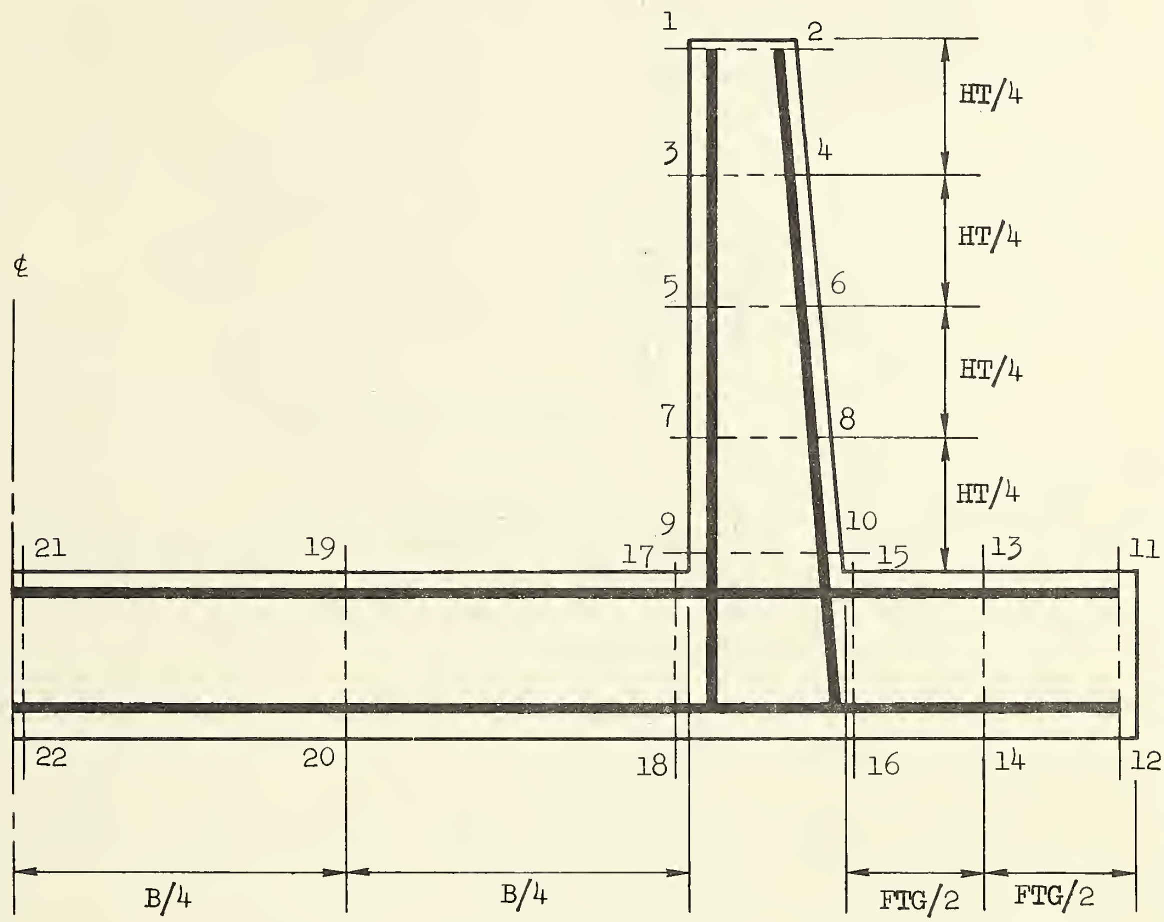


Figure 29. Type T1F steel layout and point locations.

Wall steel. LC#1 determines the steel required at the even numbered points in the wall. LC#2 determines the steel at the odd numbered points. One case of LC#1 is used for illustration. The section under consideration is located at distance, Z, from the top of the wall.

For the case illustrated, the following components of shear, in lbs per ft, are computed

$$V1 = 0.5 \times GMOIST \times K01 \times (HDIFF)^2$$

$$V2 = GMOIST \times K01 \times HDIFF \times (Z - HTW)$$

$$V3 = 0.5 \times GBUOY \times K01 \times (Z - HTW)^2$$

$$V4 = 0.5 \times 62.4 \times (Z - HTW)^2$$

then

$$VZ = V1 + V2 + V3 + V4$$

and, in ft lbs per ft

$$MZ = V1 \times (HDIFF/3 + Z - HTW) + V2 \times (Z - HTW)/2 + (V3 + V4) \times (Z - HTW)/3$$

also, in lbs per ft

$$NZ = 6.25 \times Z \times (TT + T)$$

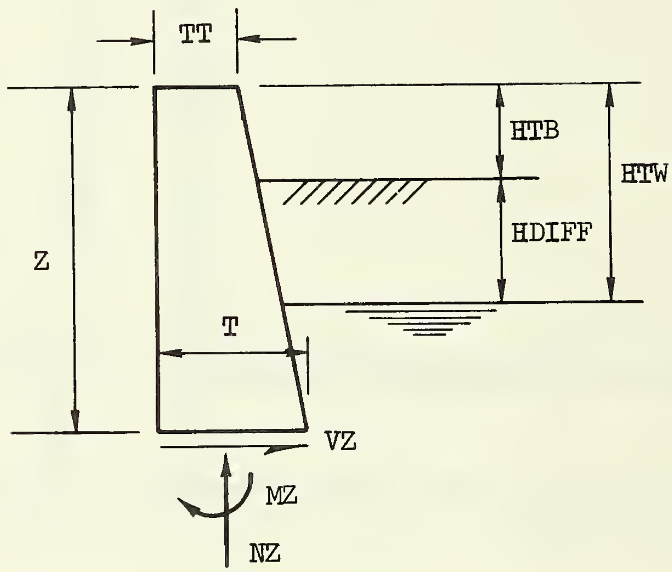


Figure 30. Wall steel design for LC#1, HB > HW1, and Z > HTW.

The required steel area for this MZ and NZ may be obtained as explained in TR-42. If the current effective depth is inadequate without using compression steel, the bottom thickness, TB, is incremented and the wall steel design is begun again. This process is repeated, as necessary, until TB exceeds its original value by 10 inches. When the effective depth is adequate, the required maximum allowable spacing, in inches, is given by

$$SZ = 10{,}015 \times (T - 2.5)/VZ$$

as explained in TR-42.

Floor slab steel. The floor slab analysis developed earlier is used to obtain shear and moment values from which steel requirements are determined at the various points in the slab. Either LC#1 or LC#2 may govern the steel at a particular point. One case of LC#1 is used to illustrate the computation of the load components on the floor slab.

The vertical wall loading, in lbs per ft, is

$$NW = 6.25 \times HT \times (TT + TB)$$

The various horizontal components of loading on the wall, in lbs per ft, are

$$H1 = 0.5 \times GMOIST \times KO1 \times (HDIFF)^2$$

$$H2 = GMOIST \times KO1 \times HDIFF \times HW1$$

$$H3 = 0.5 \times GBUOY \times KO1 \times (HW1)^2$$

$$H4 = 0.5 \times 62.4 \times (HW1)^2$$

the total horizontal loading on the wall is

$$HWALL = H1 + H2 + H3 + H4.$$

The moment brought to the floor slab by the wall, in ft lbs per ft, is

$$\begin{aligned} MW = {} & H1 \times (HDIFF/3 + HW1 + TS/24) \\ & + H2 \times (0.5 \times HW1 + TS/24) \\ & + (H3 + H4) \times (HW1/3 + TS/24) \end{aligned}$$

The direct compressive force in the footing projection, in lbs per ft, is

$$\begin{aligned} CF = {} & (KO1 \times GMOIST \times HDIFF \\ & + KO1 \times GBUOY \times (HW1 + TS/24) \\ & + 62.4 \times (HW1 + TS/24)) \times TS/12 \end{aligned}$$

The direct compressive force in the floor slab between walls, in lbs per ft, is

$$CB = CF + HWALL$$

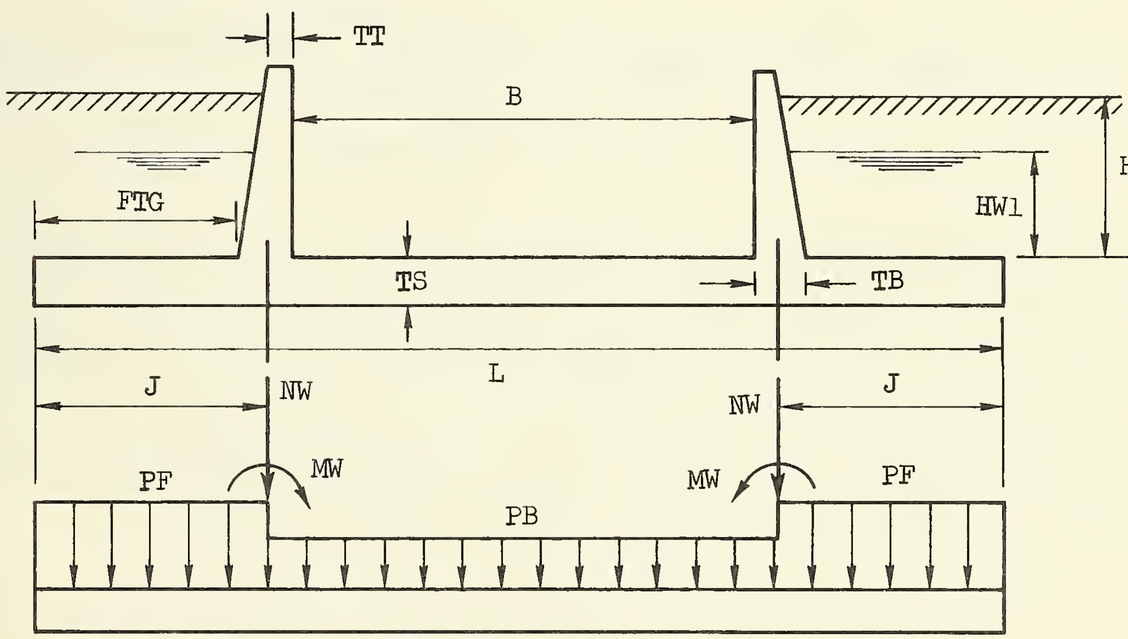


Figure 31. Floor slab analyses and loading for LC#1 when HB > HW1.

The uniform loadings on the floor slab, in psf, are

$$PB = 12.5 \times TS - 62.4 \times (HW1 + TS/12)$$

$$PF = PB + GMOIST \times HDIFF + GSAT \times HW1$$

The floor flab deflections are analyzed and the effective loading and dimensions are modified, in accordance with previous discussion, if negative deflections are discovered at the ends of the slab.

The form of the computations for shear and moment at a particular section in the floor slab depends on whether, or not, the effective span has been modified and if so, on the location of the particular section relative to the point of zero reactive pressure. If the section is outside the region of compressive reactive pressures, shear and moment are computed by statics. If the section is within the region of compressive reactive pressures, shear and moment are computed by the finite length, elastic beam relations previously developed. For example, in Figure 32 statical relations would be used at section 1, and elastic beam relations would

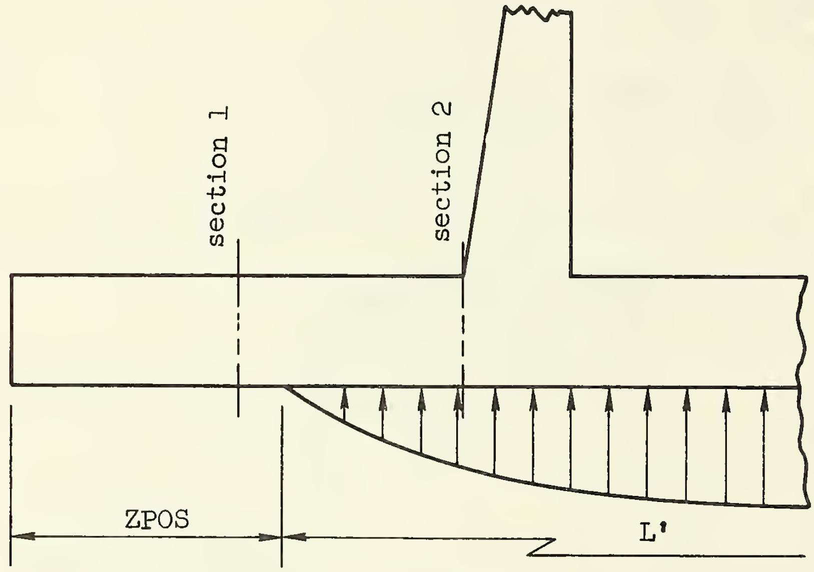


Figure 32. Determination of form of shear and moment computations.

be used at section 2. The direct compressive force is either CF or CB depending on the location of the section under consideration. The effective depth of the section is (TS - 3.5) for positive moment, that is, moment producing tension on the bottom of the slab, and (TS - 2.5) for negative moment. If the need of compression steel is indicated, the slab thickness, TS, is incremented and the slab steel design is begun again. When TS is satisfactory, the required steel area and spacing are computed for the section. For negative moment, a check is made to determine if the top steel qualifies as "top bars" with regard to spacing of steel for bond.

Type T3F
Steel areas and spacings are determined for the thirty points defined in Figure 33. A cut-off or key wall is designed at the end of the toe when necessary to ensure adequate stability against sliding of the retaining wall portion of the channel. The design of stem wall steel is the same as type T1F channels.

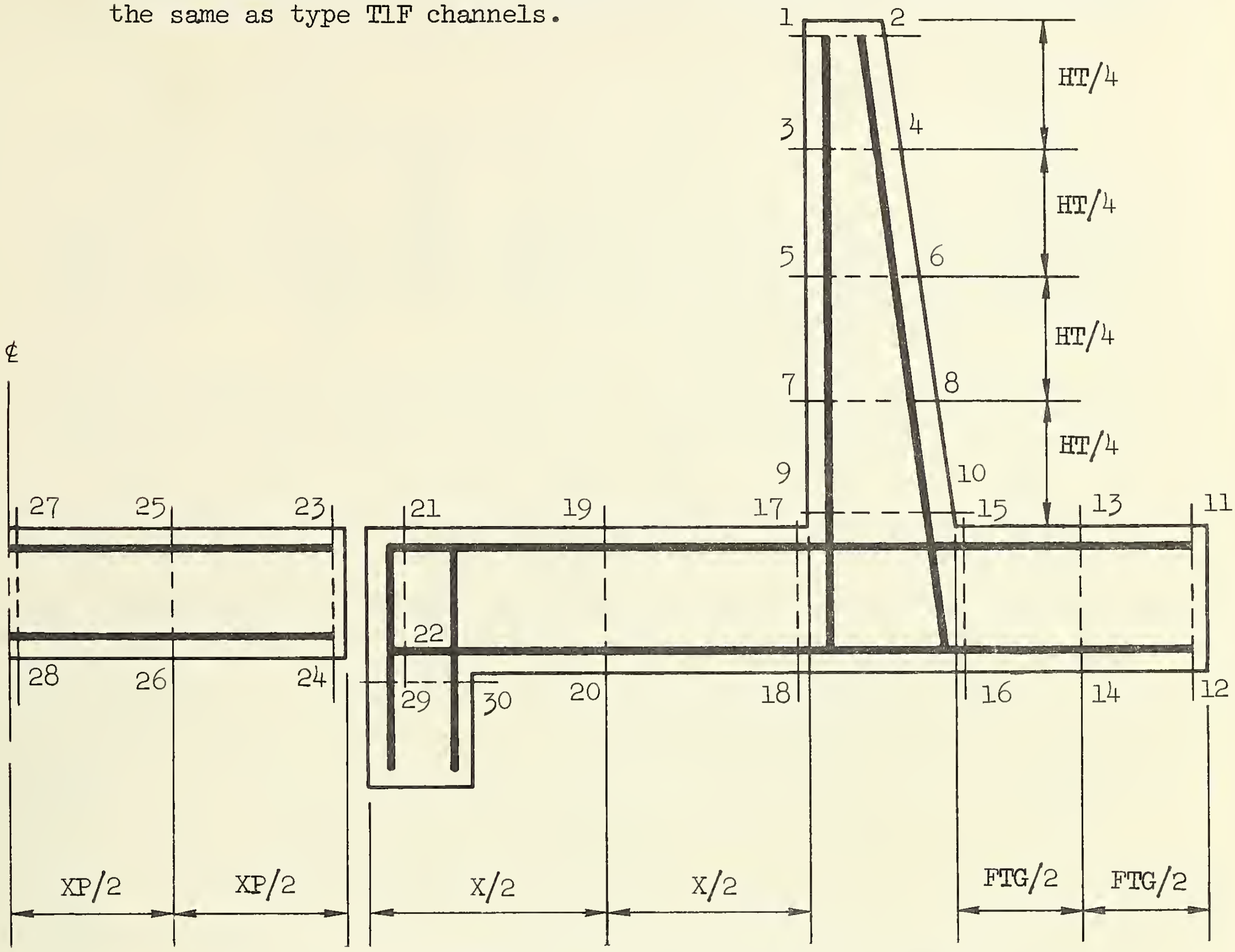


Figure 33. Type T3F steel layout and point locations.

Sliding stability of base. LC#2 produces critical conditions for sliding of the retaining wall portions of the channel. Often the base develops adequate sliding resistance without using a key wall. This check is made first. A factor of safety against sliding of 1.5 is required. The backfill is assumed capable of developing passive lateral pressures. The lateral pressure ratio is KPASS. The coefficient of friction between concrete and soil is CFSC. A waterstop between the pavement slab and the base is assumed effective at the elevation of the bottom of the base slab, thus the horizontal force due to the water in the channel, in lbs per ft, is

$$HIN = 0.5 \times 62.4 \times (HT + TS/12)^2$$

For the case shown by Figure 34, the maximum external lateral forces, in lbs per ft, are

$$H1 = 0.5 \times GMOIST \times KPASS \times (HDIFF)^2$$

$$H2 = GMOIST \times KPASS \times HDIFF \times (HW2 + TS/12)$$

H3 = 0.5 x GBUOY x KPASS x (HW2 + TS/12)^2

H4 = 0.5 x 62.4 x (HW2 + TS/12)^2

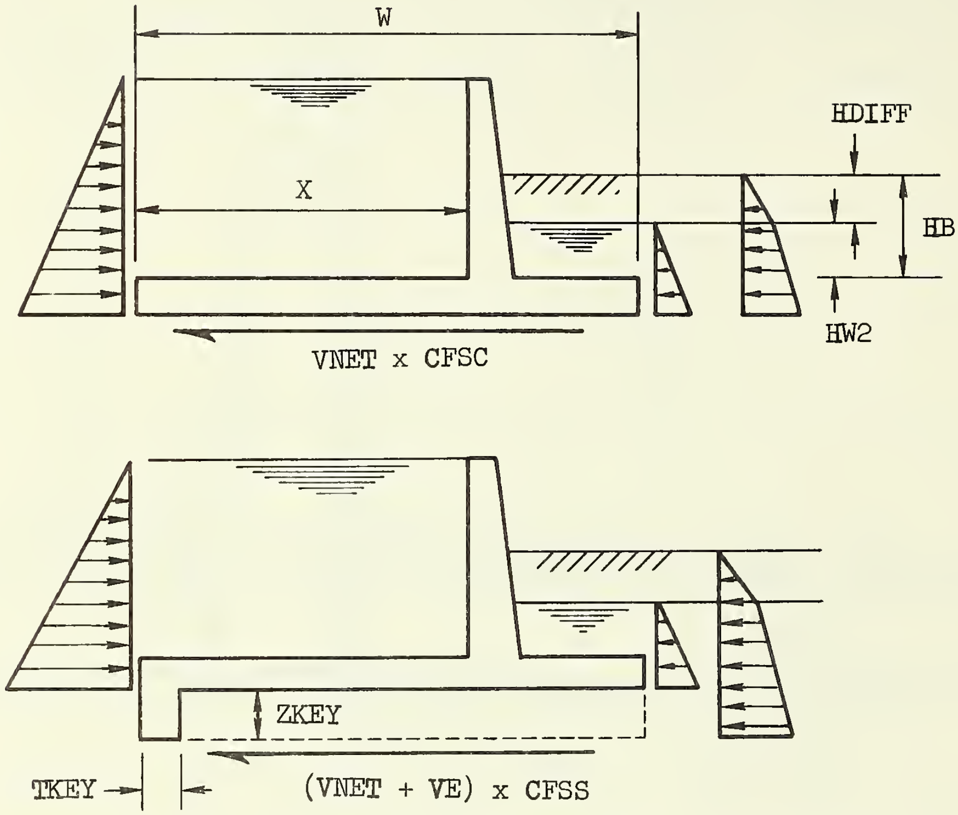


Figure 34. Sliding of type T3F retaining wall portion.

The algebraic sum of the vertical forces acting on the base portion, in lbs per ft, is

VNET = 62.4 x HT x X + 6.25 x HT x (TT + TB)
+ PFTG x FTG + 12.5 x TS x W
- 62.4 x (HW2 + TS/12) x W

The sum of the resisting horizontal forces, in lbs per ft, is

HR = H1 + H2 + H3 + H4 + VNET x CFSC

If

HR/HIN ≧ 1.5

the base does not require a key wall.

If

HR / HIN < 1.5

a key wall is required. The depth of the key wall is set initially at 1.0 ft; it will be incremented as necessary to obtain an adequate sliding safety factor. The key wall causes an additional lateral force, in lbs per ft, of

HKEY =(KPASS x GMOIST x HDIFF
+ KPASS x GBUOY x (HW2 + TS/12 + 0.5 x ZKEY)) x ZKEY

and an additional vertical force, in lbs per ft, taken as

$$VE = GBUOY \times ZKEY \times W$$

Now

$$HR = H1 + H2 + H3 + H4 + HKEY + (VNET + VE) \times CFSS$$

where CFSS is the coefficient of friction of soil to soil (equals tangent of angle of internal friction).

If

$$HR/HIN \geq 1.5$$

the current ZKEY is adequate. If

$$HR/HIN < 1.5$$

ZKEY must be incremented and another check made. Note that vertical and lateral water forces are not included in the depth ZKEY. Although present, they cancel and hence do not effect the ratio of resisting to sliding forces.

With ZKEY known, the thickness, TKEY, of the key wall is determined as follows. The force acting on the key wall over the depth, ZKEY, is very uncertain. It is taken, in lbs per ft, as

$$FKEY = ((VNET + VE) \times CFSS + HKEY)/1.5$$

Thus, on taking shear critical at the face of the support, the required thickness, in inches, is

$$TKEY = FKEY/840 + 3.5$$

The moment at the face of the support of the key wall is taken, in ft lbs per ft, as

$$MKEY = FKEY \times ZKEY/2$$

hence the required steel area at point 30 may be determined. The required spacing at point 30, in inches, is

$$S(30) = 10{,}015 \times (TKEY - 3.5)/FKEY$$

<u>Base slab steel</u>. Bearing pressures at the toe and heel of the base slab, P1 and P2, are computed as described under the preliminary design of type T3F channels. A possible resultant pressure diagram for LC#2

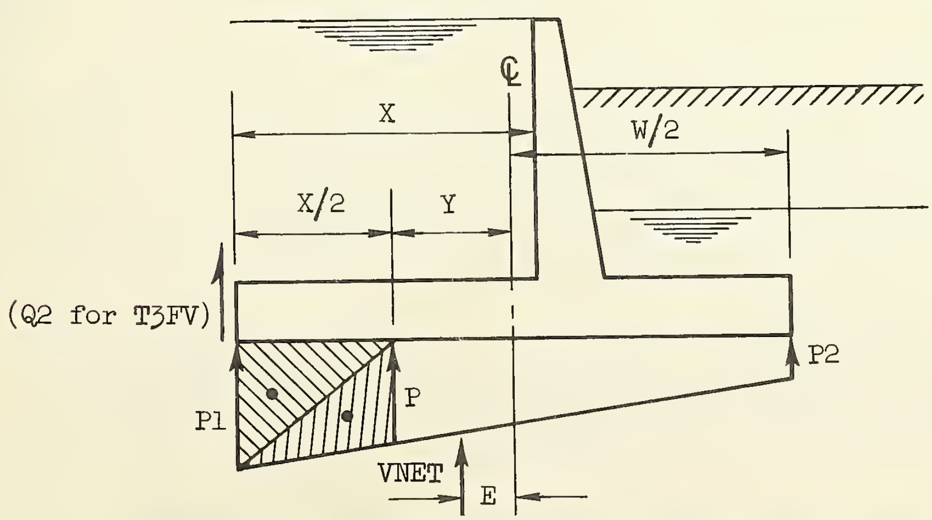


Figure 35. Contact pressure distribution for LC#2.

is shown in Figure 35. Shear, moment, and direct force are computed at the various selected sections. For example at X/2 in the toe for LC#2

$$P = (VNET/W)(1 + 12 \times E \times Y/(W \times W))$$

then the components of shear, in lbs per ft, are

$$V1 = 0.5 \times P1 \times (X/2)$$

$$V2 = 0.5 \times P \times (X/2)$$

$$V3 = (-62.4 \times HT - 12.5 \times TS + 62.4 \times (HW2 + TS/12)) \times (X/2)$$

so the total shear on the section is

$$VS = V1 + V2 + V3.$$

The moment on the section, in ft lbs per ft, is

$$MS = V1 \times (2/3) \times (X/2) + V2 \times (1/3) \times (X/2) + V3 \times (X/2)$$

Components of the direct force, in lbs per ft, are

$$H1 = 0.5 \times GMOIST \times KO2 \times (HDIFF)^2$$

$$H2 = GMOIST \times KO2 \times HDIFF \times (HW2 + TS/12)$$

$$H3 = 0.5 \times GBUOY \times KO2 \times (HW2 + TS/12)^2$$

$$H4 = 0.5 \times 62.4 \times (HW2 + TS/12)^2$$

$$H5 = 0.5 \times 62.4 \times (HT)^2$$

If a key wall is used, the direct force on the section for LC#2 is taken as

$$NS = H1 + H2 + H3 + H4 - H5$$

When the load condition is LC#1 or if there is no key wall, the frictional force is assumed uniformly distributed along the base. Hence the direct force, with no key wall, is

$$NS = (X/2)(H1 + H2 + H3 + H4 - H5)/W$$

If the moment, MS, is positive the steel area and spacing pertain to the steel at the bottom of the slab at this section. If MS is negative, the steel area and spacing pertain to the steel at the top. The base thickness, TS, is incremented if necessary and the detail design of the retaining wall portion of the channel is begun again.

Pavement slab steel. Pavement slab steel is governed by requirements for temperature and shrinkage or by direct compressive force. For LC#1 the direct compressive force in the pavement slab is taken as the maximum direct compressive force in the toe of the retaining wall base. It is assumed transferred to the pavement slab by bearing. For LC#2, the direct compressive force has two components. One is due to the water in the channel which causes pressure on the ends of the pavement slab. This force, in lbs per ft, is taken conservatively as

$$NSHT = 62.4 \times (HT + TP/24)(TP/12)$$

The other component is zero if the direct force in the retaining wall base toe is tension, otherwise the component is taken as the maximum direct compression force in the toe of the base.

Type T3FV
Steel areas and spacings are determined for the twenty eight points defined in Figure 36. The design of the stem wall is the same as type T1F channels. The remaining detail design must take account of the shear transmitted between the retaining wall bases and the pavement slab. If any thickness TB, TS, or TP, is incremented during detail

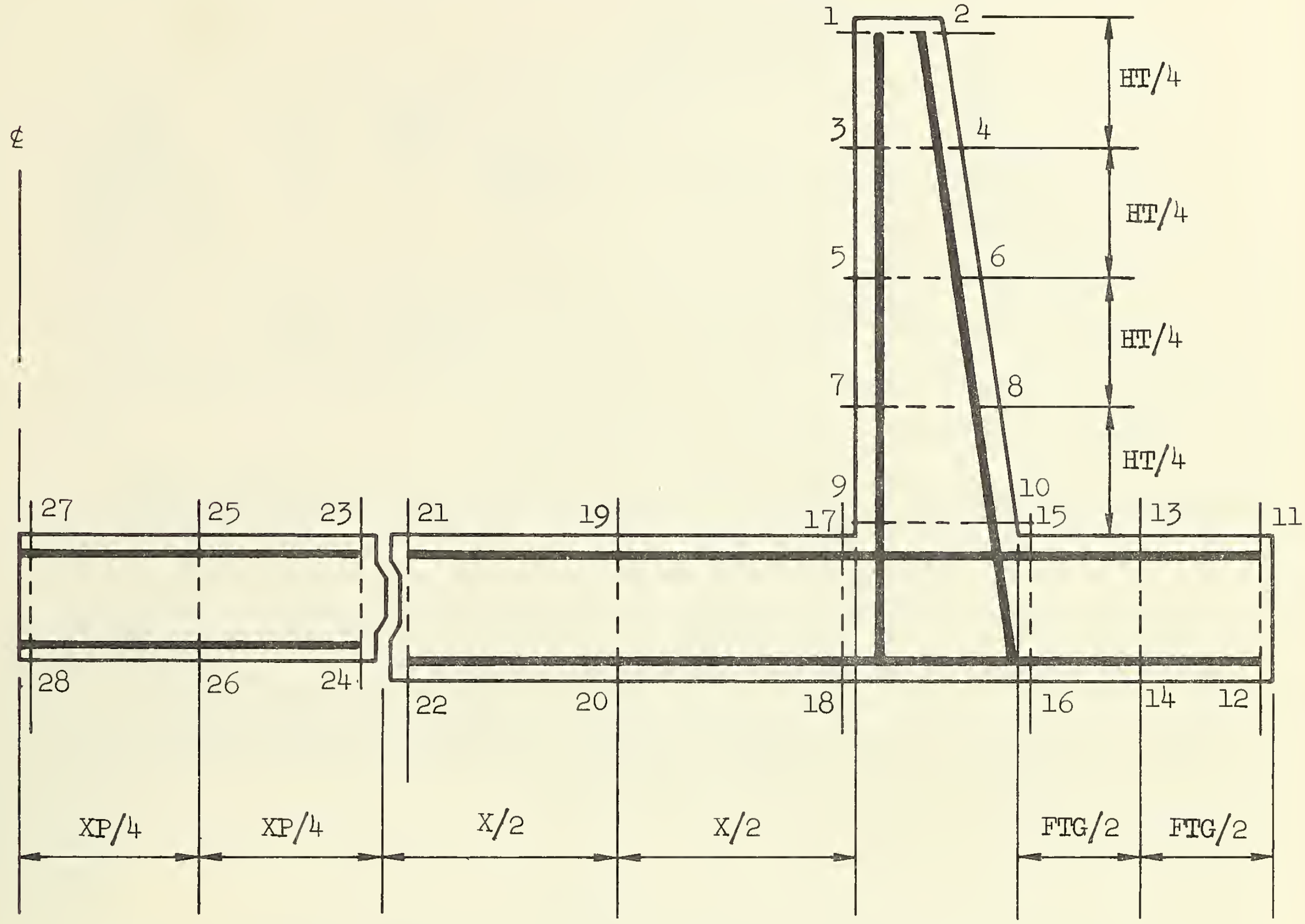


Figure 36. Type T3FV steel layout and point locations.

design, new joint shear values, Q1 and Q2 are computed and the detail design of the retaining wall base and pavement slab is performed again. This is necessary since any dimension change invalidates current Q values. The new Q values are determined by the relations given under preliminary design of type T3FV channels.

Shear joint requirements. Instead of using a key wall, type T3FV channels depend on tension steel passing through the mid-depth of the joint to provide the necessary resistance to sliding.. As with type T3F channels

$$HIN = 0.5 \times 62.4 \times (HT + TS/12)^2$$

the other lateral forces, for the case shown by Figure 37, are

H1 = 0.5 x GMOIST x KO2 x $(HDIFF)^2$

H2 = GMOIST x KO2 x HDIFF x (HW2 + TS/12)

H3 = 0.5 x GBUOY x KO2 x $(HW2 + TS/12)^2$

H4 = 0.5 x 62.4 x $(HW2 + TS/12)^2$

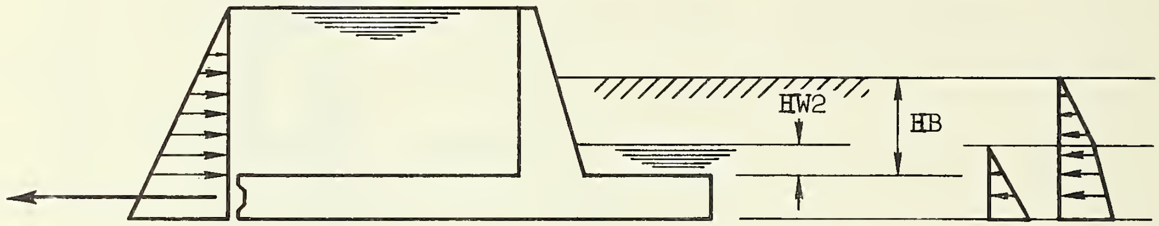


Figure 37. Direct tension through shear joint for LC#2.

Hence the required tensile steel through the joint, in sq in per ft, is

ATENS = (HIN - (H1 + H3 + H3 + H4))/20,000.

The joint must be capable of resisting the larger absolute value of Q1 and Q2. This may be provided by a concrete shear key or a combination of shear key plus steel shear area.

Base slab steel. The detail design of the steel in the base of the retaining wall portion is very similar to type T3F except that joint shear, Q1 or Q2, is present at the end of the toe. Upward joint shear on the toe is positive. The expressions for various quantities must properly include the effect of joint shear for the load condition under investigation. For instance, paralleling the discussion for type T3F, the shear and moment at X/2 in the toe for LC#2 become

VS = V1 + V2 + V3 + Q2

and

MS = (2/3 x V1 + 1/3 x V2 + V3 + Q2)(X/2).

The expression for direct force on the section depends on whether the joint between the base slab and pavement slab requires tensile steel through it or not. If tension steel is not required, a frictional force is assumed uniformly distributed along the base. If tension steel is required, no frictional force along the base is assumed. Hence NS is either

NS = (X/2)(H1 + H2 + H3 + H4 - H5)/W

or

NS = H1 + H2 + H3 + H4 - H5

If the shear joint requires tension steel, then the required steel area for points (21) and (22), in sq in per ft, is taken as

A(21) = A(22) = -0.5 x NS/20,000

The steel spacing at points (21) and (22), is governed by the signs and absolute magnitudes of Q1 and Q2. Positive Q determines spacing at point (22) whereas negative Q determines spacing at point (21).

Pavement slab steel. The pavement slab of type T3FV channels is subject to bending moment and to shear due to the transfer of joint shears. The pavement slab is assumed to act as a uniformly loaded, simple span between joints. The uniform loading is 2 x $|Q|/(XP)$. Thus at XP/4 for LC#1, the shear is

$$VS = |Q1| - (2 \times |Q1|/(XP))(XP/4)$$

the moment is

$$MS = |Q1| \times (XP/4) - 2 \times |Q1|/(XP)(XP/4)^2/2$$

and the direct force is taken as the maximum direct compressive force in the toe of the retaining wall base.

Positive Q controls steel on the top of the slab while negative Q controls bottom steel.

For LC#2 the direct force in the pavement slab has two components as described for type T3F channels. The second component is either - ATENS x 20,000 if ATENS > 0, or the maximum direct compressive force in the toe of the base if ATENS = 0.

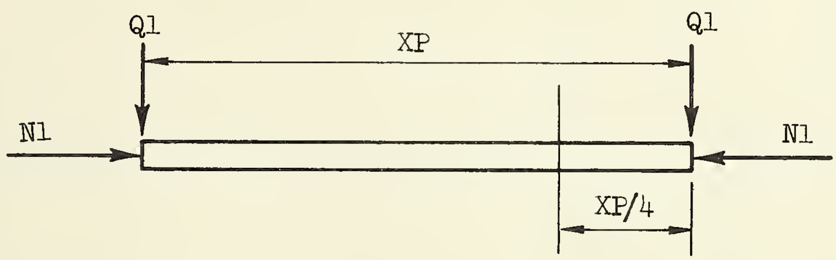


Figure 38. Pavement design for LC#1, Q1 > 0.

Type T1S

Steel areas and spacings are determined for the twenty two points, on the wall and floor slab, defined in Figure 39. Steel areas and required perimeters are also determined for the eight points, on the edge beam, defined in Figure 40. Tension and/or compression steel required

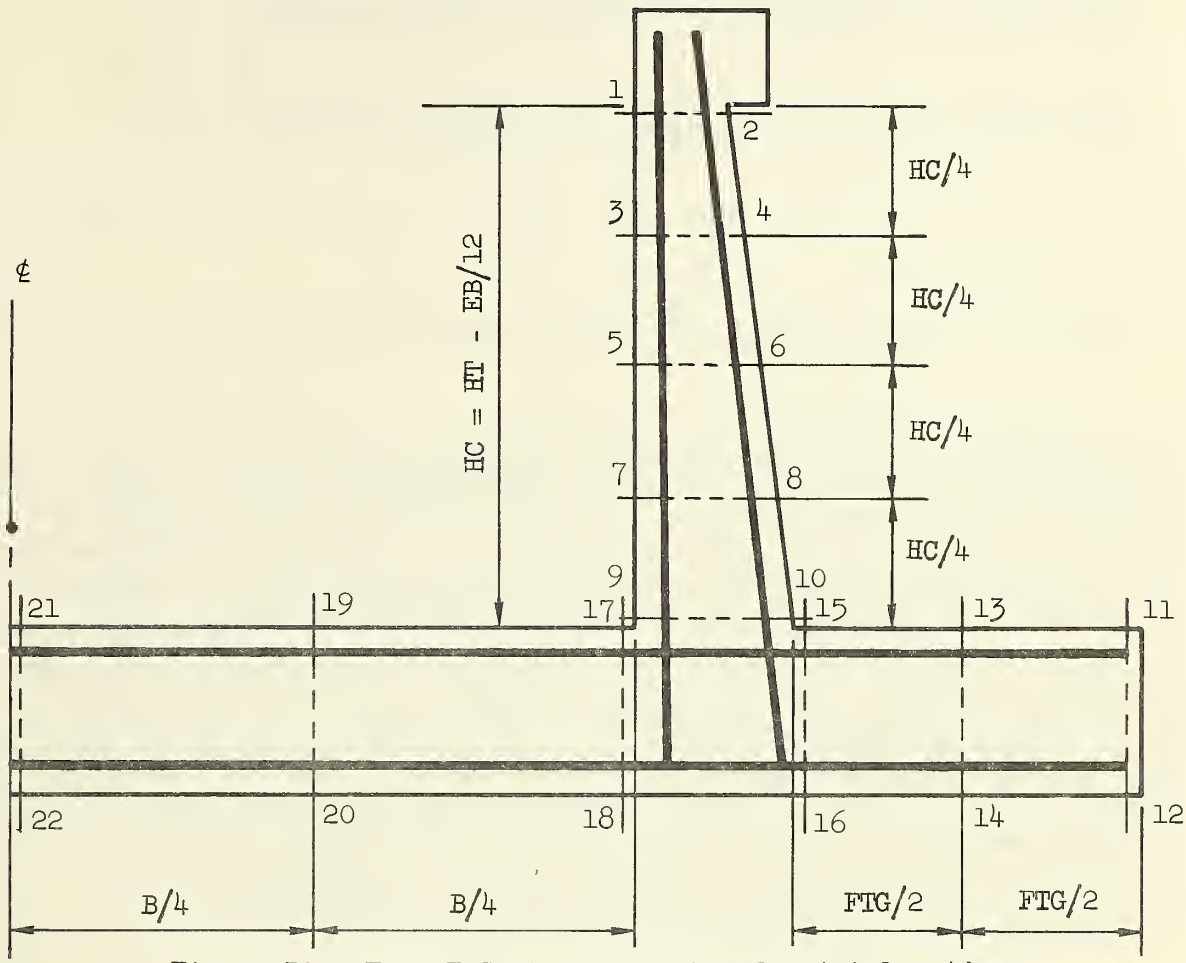


Figure 39. Type T1S steel layout and point locations.

in the struts is determined during preliminary design.

Wall and floor slab steel requirements are determined at five cross sections along the longitudinal span between transverse channel joints. These five sections are (1) the sections immediately adjacent to the transverse channel joints, (2) the sections at the struts, and (3) the section mid way between the struts. Rather than list all five (three because of symmetry) sets of steel requirements, one composite set is reported. This set consists of the maximum required area and minimum allowable spacing corresponding to each of the twenty two points in the composite section.

Whenever, in the process of detail design, it is necessary to increment either TB, TS, or ET, new edge beam loads are computed, new struts are designed, and the detail design is begun again. This is necessary since any dimension change alters existing spans, loads, and relative stiffnesses, all of which affect edge beam loading.

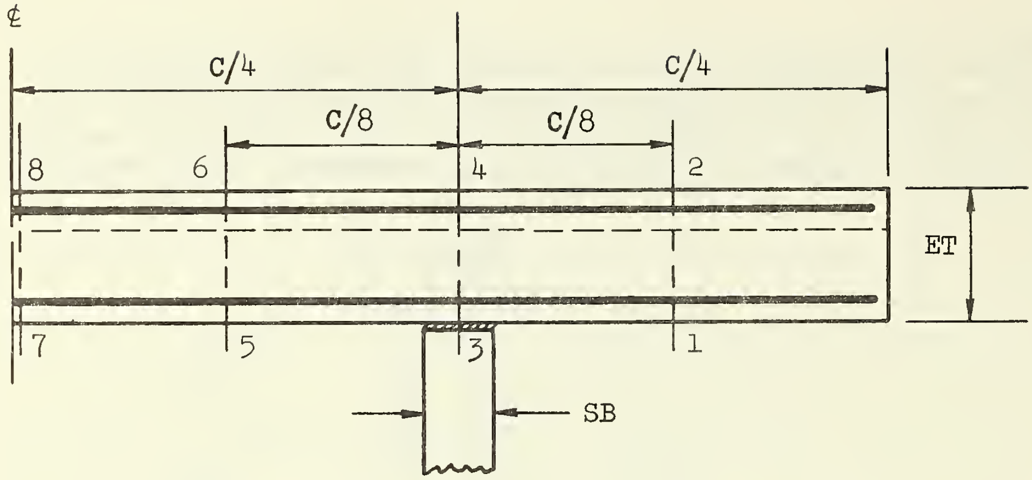


Figure 40. Plan of edge beam, steel layout and point location.

Wall steel. Design of wall steel at any one of the cross sections listed above is essentially the same as the design of type T1F walls except that the support provided the wall by the edge beam, at the particular cross section being investigated, is included in the computations for shear and moment. The direct compression force includes the weights of the struts and edge beam as well as the wall.

As previously noted, the sense of the edge beam loading may be either positive or negative for either LC#1 or LC#2. Thus the sense of the moment at any distance, Z, below the top of the wall is unpredictable. Moment expressions are therefore written such that positive moment indicates steel required at an even numbered point in the wall while negative moment indicates steel at an odd numbered point. Thus if both LC#1 and LC#2 produced negative moments at a particular Z value, the largest area and smallest spacing would be tabulated for the corresponding odd numbered point.

Floor slab steel. The design of floor slab steel at any cross-section is essentially the same as the design of type T1F floor slabs. It is only necessary to modify the expressions for MW, NW, and HWALL, see page 42, to include the effects of edge beam loadings and weights. Assume a positive edge beam loading, RX1, in lbs per ft, is added to Figure 31. Then the term -RX1 x (HT - EB/24 + TS/24) is added to the expression for MW and the term -RX1 is added to the expression for HWALL. The value of RX1 is that at the particular cross section under investigation. The term 150(ET - TT) x EB/144 plus a term accounting for strut weight is added to the expression for NW. With these changes, the analysis proceeds as described for type T1F channel floor slabs.

Edge beam steel. A summation process is used to obtain the shears and moments at the one-eighth points of the edge beam span. Either load condition can produce moments of either sense at any section of the span. Hence an approach similar to that indicated for the wall steel is used here to determine critical steel requirements at the odd and even numbered points shown in Figure 40.

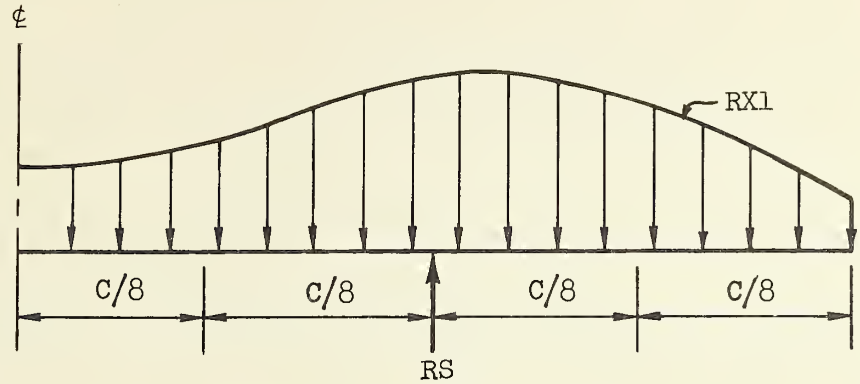


Figure 41. Edge beam loading for LC#1 when RX1 > 0.

The procedure used to obtain required steel area is based on a moment per foot of width. Hence, if the moment at a section of the edge beam is M ft lbs, the equivalent moment per foot of width is

$$ME = M/(EB/12)$$

from which the required area per foot of width is obtained, if this is AE, the total required area at the section, in sq. inches, is

$$A = AE \times (EB/12).$$

Flexural bond requirements are satisfied by determining the steel perimeter required at the eight edge beam points. For any shear, V, in lbs, the required perimeter, Σo, in inches, is taken as

$$\Sigma o = \frac{V}{ujD} = \frac{V}{347 \times 7/8 \times D} = \frac{V}{303.6 \times D}$$

The allowable bond stress for #7 bars is used. Thus the computed perimeter is conservative for all bars of equal or smaller diameter than #7.

Edge beam stirrups. When edge beam web steel is required for diagonal tension, the maximum shear stress is not allowed to exceed $3\sqrt{f'_c} = 190$ psi. EB may need to be incremented, and ET recomputed, to hold the shear stress to this limit. Maximum allowable spacing of the web steel is then the smallest of:

$S = D/2$	ACI	1206(a)
$S = AV/(0.0015 \times EB)$	ACI	1206(b)
$S = 20000 \times AV \times D/VRP$	ACI	1203

in which

$$VRP = V - 70 \times EB \times D$$

where

V = shear at section under investigation, in lbs per ft

VPR = shear carried by web steel, in lbs per ft

D = effective depth, in inches

AV = area of web steel, twice the bar area, in sq inches

S = maximum allowable web steel spacing, in inches

AV is initially set at 0.22 sq in for #3 stirrups. If S, for this area, is less than 4 inches, the stirrup size is increased to #4, the spacing is recomputed, etc. Although the maximum allowable spacing may be computed at either sections D distance from the faces of the supports or the section at the centerline of the support, the spacing is conservatively reported as that at D from the faces.

The web steel layout may be selected by consideration of a diagram similar to that of Figure 42. The ordinates of the diagram are required values of AV/S. They may be assumed to vary linearly from zero to a maximum over the supports. The ordinate at D from the faces of the strut is obtained from the required stirrup size and spacing computed above.

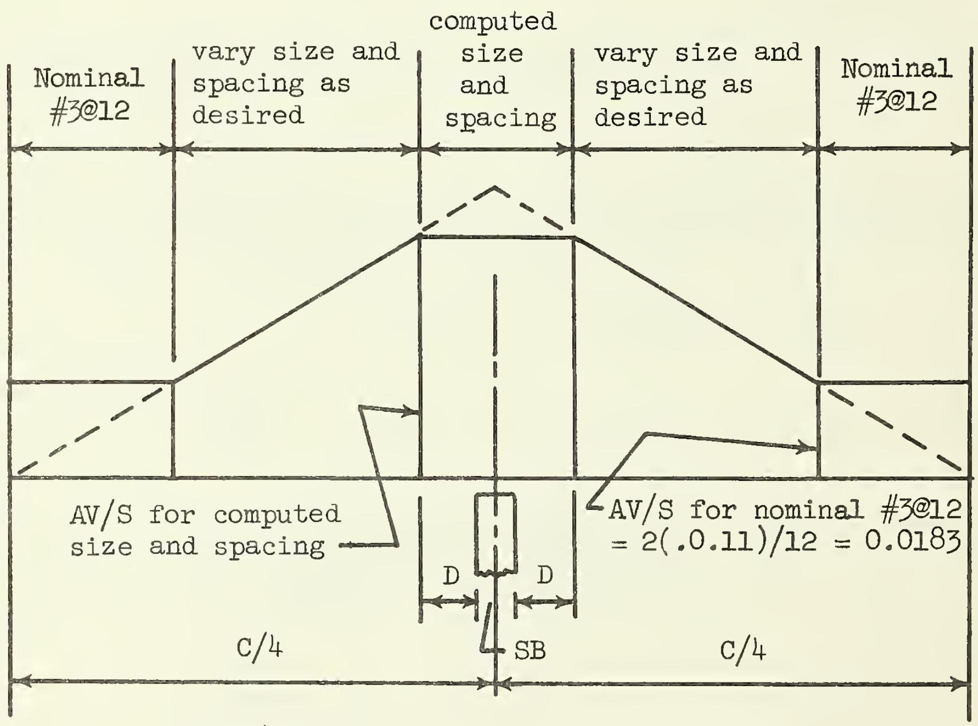


Figure 42. Layout of edge beam stirrups.

Computer Designs

Input

From one to four lines of input data are required for each design run. A given computer job may include many design runs. A design run is made for a particular set of design conditions and takes one of two forms. The first form consists of four preliminary designs, one for each channel type, plus an indication of the channel type that might be selected for detail design on the basis of least concrete volume. The second form concists of the detail design of one of the four channel types.

The input data provided per design run consists essentially of values for the primary design parameters and, if desired, values for the secondary design parameters. Table 2 shows the lines that may be provided per run together with the specific parameters contained on the four lines.

Table 2. Input values per design run

B	HT	HB	DESIGN	DEFAULT 1	DEFAULT 2	DEFAULT 3	
HW1	HW2	HWP	GMOIST	GSAT	KO1	KO2	FLOATR
MAXFTG	JOINTS	MFOUND					
CFSC	CFSS	KPASS					

The first line contains the primary parameters B, HT, and HB and is always required. If DESIGN = 0, the four preliminary designs are performed. If DESIGN = 1, 2, 3, or 4, then the detail design of type T1F, T3F, T3FV, or T1S is performed. (If desired, the Design Unit can run the detail design of the structural channel type indicated from the preliminary designs. However, it will often be a better procedure if the concerned designer will take a critical look at the preliminary design results before a detail design is run.)

If DEFAULT 1 > 0, the next line of input data must be provided, it contains values for HW1 through FLOATR as indicated. If DEFAULT 1 = 0, this line of input data must not be included, default values for the eight parameters will be provided by the computer.

If DEFAULT 2 > 0, the next line containing values for MAXFTG, JOINTS, and MFOUND must be provided. If DEFAULT 2 = 0, default values will be used and the line must be omitted, similarly for DEFAULT 3 and the line containing CFSC, CFSS, and KPASS.

Thus the number of lines of data that must be provided per design run will vary depending on whether the default values are satisfactory or whether the user wishes to supply some or all of the secondary parameter values. Note that although various lines may be omitted, those supplied must be complete and in the order indicated.

Output

The output for each design run, whether preliminary designs or a detail design, gives the parameter values assumed for that run. These parameters are listed and identified at the beginning of the design.

Preliminary designs. Preliminary design results are listed in the order T1F, T3F, T3FV, and T1S, see Figure 43. Output values consist of distances, thicknesses, and concrete volumes in cubic yards per longitudinal foot of channel. The thicknesses and distances, in inches and feet, may be identified by reference to various figures:

for type T1F see Figures 5 and 6
for type T3F see Figures 5, 7, and 9
for type T3FV see Figures 5, 7, and 9
for type T1S see Figure 13.

Detail Designs. The output for the detail design of any channel type includes three segments: a repeat of the preliminary design results, a similar output giving final dimensions (this will often be identical to the preliminary design values), and a listing of steel requirements giving required area and maximum allowable spacing in sq. in. per ft and inches.

Type T1F. - See Figures 44 and 45 for output examples, see Figure 29 for the steel locations listed.

Type T3F. - See Figures 46 and 47 for output examples, see Figure 33 for the steel locations listed. Note that a key wall is required in Figure 47, the required depth of the wall is given in ft and the required thickness of the wall is given in inches.

Type T3FV. - See Figures 48 and 49 for output examples, see Figure 36 for the steel locations listed. Note that the shear forces transmitted across the shear joint are given in lbs per ft for LC#1 and LC#2. The tension steel area, in sq inches per ft, through the joint is also given.

Type T1S. - See Figures 50 and 51 for output examples, see Figures 39 and 40 for wall and edge beam steel locations. Required strut steel areas, in sq inches, are given for tension and compression. Required edge beam web steel is given by bar size and spacing in inches. Required edge beam longitudinal steel areas, in sq inches, and perimeters, in inches, are given for eight locations.

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                      RECTANGULAR STRUCTURAL CHANNEL
                           CROSS SECTION DESIGN
             ELASTIC ANALYSIS AND WORKING STRESS DESIGN ARE USED

        SPECIAL DESIGN PREPARED BY THE DESIGN UNIT AT HYATTSVILLE, MD.
                                   FOR

       EXAMPLE SPECIAL DESIGNS FOR STRUCTURAL CHANNEL TECHNICAL RELEASE
       JOAN FOR ESA --------- 2/29/72

                DESIGN PARAMETERS
  B= 24.00        HW1= 12.00       KO1= 0.80    FLOATR=  1.50   MFOUND= 100000.
 HT= 16.00        HW2=  1.50       KO2= 0.20    JOINTS= 40.00   GMOIST=    120.
 HB= 15.00        HWP= 12.00     KPASS= 1.25    MAXFTG= 12.00     GSAT=    140.
                                  CFSC= 0.35      CFSS=  0.55

                PRELIMINARY DESIGNS FOLLOW

                TYPE T1F STRUCTURAL CHANNEL - TRIAL VALUES
 TT= 10.00         TB= 19.00        TS= 20.00  FTG PROJ=11.00   QUANT=  4.467

                TYPE T3F STRUCTURAL CHANNEL - TRIAL VALUES
  X= 10.00         TP= 90.00        XP=  4.00
 TT= 10.00         TB= 19.00        TS= 20.00  FTG PROJ= 9.00   QUANT=  5.084

                TYPE T3FV STRUCTURAL CHANNEL - TRIAL VALUES
  X=  3.00         TP= 30.00        XP= 18.00
 TT= 10.00         TB= 19.00        TS= 20.00  FTG PROJ=12.00   QUANT=  5.146

                TYPE T1S STRUCTURAL CHANNEL - TRIAL VALUES
 SB= 12.00         ST= 15.00        EB= 15.00        ET= 26.00
 TT= 10.00         TB= 21.00        TS= 22.00  FTG PROJ=10.40   QUANT=  4.990

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

TYPE  T1F STRUCTURAL CHANNEL MIGHT BE SELECTED FOR DETAIL DESIGN, QUANT= 4.467

========================== END PRELIMINARY DESIGNS ========================

==========================================================================

                      RECTANGULAR STRUCTURAL CHANNEL
                           CROSS SECTION DESIGN
             ELASTIC ANALYSIS AND WORKING STRESS DESIGN ARE USED

        SPECIAL DESIGN PREPARED BY THE DESIGN UNIT AT HYATTSVILLE, MD.
                                   FOR

       EXAMPLE SPECIAL DESIGNS FOR STRUCTURAL CHANNEL TECHNICAL RELEASE
       JOAN FOR ESA --------- 2/29/72

                DESIGN PARAMETERS
  B= 24.00        HW1=  0.0        KO1= 0.80    FLOATR=  1.50   MFOUND= 100000.
 HT= 16.00        HW2=  0.0        KO2= 0.20    JOINTS= 40.00   GMOIST=    120.
 HB= 15.00        HWP=  0.0      KPASS= 1.25    MAXFTG= 12.00     GSAT=    140.
                                  CFSC= 0.35      CFSS=  0.55

                PRELIMINARY DESIGNS FOLLOW

                TYPE T1F STRUCTURAL CHANNEL - TRIAL VALUES
 TT= 10.00         TB= 18.00        TS= 19.00  FTG PROJ= 0.0    QUANT=  2.966

                TYPE T3F STRUCTURAL CHANNEL - TRIAL VALUES
  X= 12.00         TP= 11.00        XP= -0.0
 TT= 10.00         TB= 18.00        TS= 19.00  FTG PROJ= 2.80   QUANT=  3.294

                TYPE T3FV STRUCTURAL CHANNEL - TRIAL VALUES
  X=  5.00         TP= 11.00        XP= 14.00
 TT= 10.00         TB= 18.00        TS= 19.00  FTG PROJ= 4.60   QUANT=  3.160

                TYPE T1S STRUCTURAL CHANNEL - TRIAL VALUES
 SB= 12.00         ST= 15.00        EB= 15.00        ET= 23.00
 TT= 10.00         TB= 12.00        TS= 13.00  FTG PROJ= 0.0    QUANT=  2.285

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

TYPE  T1S STRUCTURAL CHANNEL MIGHT BE SELECTED FOR DETAIL DESIGN, QUANT= 2.285

========================== END PRELIMINARY DESIGNS ========================
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Figure 43. Computer output, preliminary designs.

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                     RECTANGULAR STRUCTURAL CHANNEL
                          CROSS SECTION DESIGN
          ELASTIC ANALYSIS AND WORKING STRESS DESIGN ARE USED

      SPECIAL DESIGN PREPARED BY THE DESIGN UNIT AT HYATTSVILLE, MD.
                                  FOR

     EXAMPLE SPECIAL DESIGNS FOR STRUCTURAL CHANNEL TECHNICAL RELEASE
     JOAN FOR ESA --------- 2/29/72

              DESIGN PARAMETERS
  B= 24.00      HW1=  0.0      KO1= 0.80    FLOATR=  1.50   MFOUND= 100000.
 HT= 16.00      HW2=  0.0      KO2= 0.20    JOINTS= 40.00   GMOIST=    120.
 HB= 15.00      HWP=  0.0    KPASS= 1.25    MAXFTG= 12.00     GSAT=    140.
                              CFSC= 0.35      CFSS=  0.55

              DESIGN OF SPECIFIED TYPE FOLLOWS

              TYPE T1F STRUCTURAL CHANNEL - TRIAL VALUES
 TT= 10.00       TB= 18.00       TS= 19.00  FTG PROJ= 0.0     QUANT=  2.966

              TYPE T1F STRUCTURAL CHANNEL - DETAIL DESIGN
 TT= 10.00       TB= 18.00       TS= 20.00  FTG PROJ= 0.0     QUANT=  3.049

              STEEL REQUIREMENTS
        WALL
                 A( 1)=  0.24                S( 1)= 18.00
                 A( 2)=  0.24                S( 2)= 18.00
                 A( 3)=  0.29                S( 3)= 18.00
                 A( 4)=  0.14                S( 4)= 18.00
                 A( 5)=  0.34                S( 5)= 18.00
                 A( 6)=  0.27                S( 6)= 18.00
                 A( 7)=  0.55                S( 7)= 18.00
                 A( 8)=  0.99                S( 8)= 18.00
                 A( 9)=  1.17                S( 9)= 18.00
                 A(10)=  2.31                S(10)= 14.37
        BASE
                 A(11) - A(16) DO NOT EXIST SINCE FTG=0

                 A(17)=  1.45                S(17)= 18.00
                 A(18)=  2.16                S(18)= 18.00
                 A(19)=  1.47                S(19)= 18.00
                 A(20)=  1.33                S(20)= 18.00
                 A(21)=  1.34                S(21)= 18.00
                 A(22)=  0.90                S(22)= 18.00

=============================== END T1F DESIGN ==============================
```

Figure 44, Computer output, type T1F detail design

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                    RECTANGULAR STRUCTURAL CHANNEL
                         CROSS SECTION DESIGN
          ELASTIC ANALYSIS AND WORKING STRESS DESIGN ARE USED

      SPECIAL DESIGN PREPARED BY THE DESIGN UNIT AT HYATTSVILLE, MD.
                                 FOR

     EXAMPLE SPECIAL DESIGNS FOR STRUCTURAL CHANNEL TECHNICAL RELEASE
     JOAN FOR ESA --------- 2/29/72

              DESIGN PARAMETERS
  B= 24.00      HW1= 12.00       KO1= 0.80    FLOATR=  1.50   MFOUND= 100000.
 HT= 16.00      HW2=  1.50       KO2= 0.20    JOINTS= 40.00   GMOIST=     120.
 HB= 15.00      HWP= 12.00     KPASS= 1.25    MAXFTG= 12.00     GSAT=     140.
                                CFSC= 0.35      CFSS=  0.55

              DESIGN OF SPECIFIED TYPE FOLLOWS

              TYPE T1F STRUCTURAL CHANNEL - TRIAL VALUES
 TT= 10.00        TB= 19.00       TS= 20.00  FTG PROJ=11.00   QUANT=  4.467

              TYPE T1F STRUCTURAL CHANNEL - DETAIL DESIGN
 TT= 10.00        TB= 19.00       TS= 20.00  FTG PROJ=11.00   QUANT=  4.467

              STEEL REQUIREMENTS
         WALL
                  A( 1)=  0.24                S( 1)= 18.00
                  A( 2)=  0.24                S( 2)= 18.00
                  A( 3)=  0.29                S( 3)= 18.00
                  A( 4)=  0.15                S( 4)= 18.00
                  A( 5)=  0.35                S( 5)= 18.00
                  A( 6)=  0.27                S( 6)= 18.00
                  A( 7)=  0.52                S( 7)= 18.00
                  A( 8)=  1.05                S( 8)= 18.00
                  A( 9)=  1.08                S( 9)= 18.00
                  A(10)=  2.50                S(10)= 12.86
         BASE
                  A(11)=  0.24                S(11)= 18.00
                  A(12)=  0.24                S(12)= 18.00
                  A(13)=  0.24                S(13)= 18.00
                  A(14)=  0.25                S(14)= 18.00
                  A(15)=  0.92                S(15)= 18.00
                  A(16)=  0.55                S(16)= 18.00

                  A(17)=  0.89                S(17)= 18.00
                  A(18)=  0.63                S(18)= 18.00
                  A(19)=  1.11                S(19)= 18.00
                  A(20)=  0.24                S(20)= 18.00
                  A(21)=  1.07                S(21)= 18.00
                  A(22)=  0.24                S(22)= 18.00
============================= END T1F DESIGN =============================
```

Figure 45, Computer output, type T1F detail design.

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=================================================================
                    RECTANGULAR STRUCTURAL CHANNEL
                         CROSS SECTION DESIGN
           ELASTIC ANALYSIS AND WORKING STRESS DESIGN ARE USED

       SPECIAL DESIGN PREPARED BY THE DESIGN UNIT AT HYATTSVILLE, MD.
                                 FOR

      EXAMPLE SPECIAL DESIGNS FOR STRUCTURAL CHANNEL TECHNICAL RELEASE
      JOAN FOR ESA --------- 2/29/72

             DESIGN PARAMETERS
 B= 24.00      HW1=  0.0       KO1= 0.80   FLOATR=  1.50  MFOUND= 100000.
HT= 16.00      HW2=  0.0       KO2= 0.20   JOINTS= 40.00  GMOIST=    120.
HB=  4.00      HWP=  0.0     KPASS= 1.25   MAXFTG= 12.00    GSAT=    140.
                              CFSC= 0.35     CFSS=  0.55

             DESIGN OF SPECIFIED TYPE FOLLOWS

             TYPE T3F STRUCTURAL CHANNEL - TRIAL VALUES
 X= 10.00       TP= 11.00      XP=  4.00
TT= 10.00       TB= 16.00      TS= 17.00  FTG PROJ= 4.60   QUANT=  3.092

             TYPE T3F STRUCTURAL CHANNEL - DETAIL DESIGN
 X= 10.00       TP= 11.00      XP=  4.00
TT= 10.00       TB= 16.00      TS= 17.00  FTG PROJ= 4.60   QUANT=  3.265

             STEEL REQUIREMENTS
        WALL
                A( 1)=  0.24            S( 1)= 18.00
                A( 2)=  0.24            S( 2)= 18.00
                A( 3)=  0.28            S( 3)= 18.00
                A( 4)=  0.28            S( 4)= 18.00
                A( 5)=  0.31            S( 5)= 18.00
                A( 6)=  0.31            S( 6)= 18.00
                A( 7)=  0.94            S( 7)= 18.00
                A( 8)=  0.35            S( 8)= 18.00
                A( 9)=  2.08            S( 9)= 17.34
                A(10)=  0.19            S(10)= 18.00
        BASE
                A(11)=  0.20            S(11)= 18.00
                A(12)=  0.20            S(12)= 18.00
                A(13)=  0.20            S(13)= 18.00
                A(14)=  0.20            S(14)= 18.00
                A(15)=  0.20            S(15)= 18.00
                A(16)=  0.65            S(16)= 18.00

                A(17)=  1.75            S(17)= 18.00
                A(18)=  0.20            S(18)= 18.00
                A(19)=  0.70            S(19)= 18.00
                A(20)=  0.20            S(20)= 18.00
                A(21)=  0.41            S(21)= 18.00
                A(22)=  0.20            S(22)= 18.00

        KEY WALL
                DEPTH=  2.00
                THICK= 14.00
                A(29)=  0.17            S(29)= 18.00
                A(30)=  0.50            S(30)= 12.87
        PAVEMENT SLAB
                A(23)=  0.26            S(23)= 18.00
                A(24)=  0.13            S(24)= 18.00
                A(25)=  0.26            S(25)= 18.00
                A(26)=  0.13            S(26)= 18.00
                A(27)=  0.26            S(27)= 18.00
                A(28)=  0.13            S(28)= 18.00

============================ END T3F DESIGN ============================
```

Figure 46. Computer output, type T3F detail design.

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                    RECTANGULAR STRUCTURAL CHANNEL
                         CROSS SECTION DESIGN
          ELASTIC ANALYSIS AND WORKING STRESS DESIGN ARE USED

       SPECIAL DESIGN PREPARED BY THE DESIGN UNIT AT HYATTSVILLE, MD.
                                 FOR

      EXAMPLE SPECIAL DESIGNS FOR STRUCTURAL CHANNEL TECHNICAL RELEASE
      JOAN FOR ESA --------- 2/29/72

               DESIGN PARAMETERS
  B= 24.00       HW1= 12.00       KO1= 0.80     FLOATR=  1.50   MFOUND= 100000.
 HT= 16.00       HW2=  1.50       KO2= 0.20     JOINTS= 40.00   GMOIST=    120.
 HB= 15.00       HWP= 12.00     KPASS= 1.25     MAXFTG= 12.00     GSAT=    140.
                                 CFSC= 0.35       CFSS=  0.55

               DESIGN OF SPECIFIED TYPE FOLLOWS

               TYPE T3F STRUCTURAL CHANNEL - TRIAL VALUES
  X= 10.00       TP= 90.00       XP=  4.00
 TT= 10.00       TB= 19.00       TS= 20.00  FTG PROJ= 9.00   QUANT=  5.084

               TYPE T3F STRUCTURAL CHANNEL - DETAIL DESIGN
  X= 10.00       TP= 90.00       XP=  4.00
 TT= 10.00       TB= 19.00       TS= 20.00  FTG PROJ= 9.00   QUANT=  5.084

               STEEL REQUIREMENTS
          WALL
                 A( 1)=  0.24              S( 1)= 18.00
                 A( 2)=  0.24              S( 2)= 18.00
                 A( 3)=  0.29              S( 3)= 18.00
                 A( 4)=  0.15              S( 4)= 18.00
                 A( 5)=  0.35              S( 5)= 18.00
                 A( 6)=  0.27              S( 6)= 18.00
                 A( 7)=  0.52              S( 7)= 18.00
                 A( 8)=  1.05              S( 8)= 18.00
                 A( 9)=  1.08              S( 9)= 18.00
                 A(10)=  2.50              S(10)= 12.86
          BASE
                 A(11)=  0.24              S(11)= 18.00
                 A(12)=  0.24              S(12)= 18.00
                 A(13)=  0.28              S(13)= 18.00
                 A(14)=  0.24              S(14)= 18.00
                 A(15)=  1.31              S(15)= 16.43
                 A(16)=  0.58              S(16)= 18.00

                 A(17)=  0.71              S(17)= 18.00
                 A(18)=  1.47              S(18)= 18.00
                 A(19)=  0.48              S(19)= 18.00
                 A(20)=  0.27              S(20)= 18.00
                 A(21)=  0.48              S(21)= 18.00
                 A(22)=  0.24              S(22)= 18.00

          KEY WALL NOT REQUIRED

          PAVEMENT SLAB
                 A(23)=  0.77              S(23)= 18.00
                 A(24)=  0.38              S(24)= 18.00
                 A(25)=  0.77              S(25)= 18.00
                 A(26)=  0.38              S(26)= 18.00
                 A(27)=  0.77              S(27)= 18.00
                 A(28)=  0.38              S(28)= 18.00

========================== END T3F DESIGN ================================
```

Figure 47. Computer output, type T3F detail design.

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                RECTANGULAR STRUCTURAL CHANNEL
                     CROSS SECTION DESIGN
          ELASTIC ANALYSIS AND WORKING STRESS DESIGN ARE USED

      SPECIAL DESIGN PREPARED BY THE DESIGN UNIT AT HYATTSVILLE, MD.
                                FOR

     EXAMPLE SPECIAL DESIGNS FOR STRUCTURAL CHANNEL TECHNICAL RELEASE
     JOAN FOR ESA --------- 2/29/72

               DESIGN PARAMETERS
  B= 24.00        HW1=  0.0       KO1= 0.80    FLOATR=  1.50   MFOUND= 100000.
 HT= 16.00        HW2=  0.0       KO2= 0.20    JOINTS= 40.00   GMOIST=    120.
 HB= 15.00        HWP=  0.0     KPASS= 1.25    MAXFTG= 12.00     GSAT=    140.
                                 CFSC= 0.35      CFSS=  0.55

               DESIGN OF SPECIFIED TYPE FOLLOWS

               TYPE T3FV STRUCTURAL CHANNEL - TRIAL VALUES
  X=  5.00        TP= 11.00       XP= 14.00
 TT= 10.00        TB= 18.00       TS= 19.00  FTG PROJ= 4.60   QUANT=  3.160

               TYPE T3FV STRUCTURAL CHANNEL - DETAIL DESIGN
  X=  5.00        TP= 13.00       XP= 14.00
 TT= 10.00        TB= 18.00       TS= 19.00  FTG PROJ= 4.60   QUANT=  3.246

               STEEL REQUIREMENTS
          WALL
                  A( 1)=  0.24              S( 1)= 18.00
                  A( 2)=  0.24              S( 2)= 18.00
                  A( 3)=  0.29              S( 3)= 18.00
                  A( 4)=  0.14              S( 4)= 18.00
                  A( 5)=  0.34              S( 5)= 18.00
                  A( 6)=  0.27              S( 6)= 18.00
                  A( 7)=  0.55              S( 7)= 18.00
                  A( 8)=  0.99              S( 8)= 18.00
                  A( 9)=  1.17              S( 9)= 18.00
                  A(10)=  2.31              S(10)= 14.37
          BASE
                  A(11)=  0.23              S(11)= 18.00
                  A(12)=  0.23              S(12)= 18.00
                  A(13)=  0.23              S(13)= 18.00
                  A(14)=  0.23              S(14)= 18.00
                  A(15)=  0.66              S(15)= 15.16
                  A(16)=  0.42              S(16)= 18.00

                  A(17)=  0.97              S(17)= 18.00
                  A(18)=  1.45              S(18)= 15.66
                  A(19)=  0.54              S(19)= 18.00
                  A(20)=  0.41              S(20)= 18.00
                  A(21)=  0.46              S(21)= 18.00
                  A(22)=  0.23              S(22)= 18.00

          SHEAR CONNECTION
                  REQD TENSION STEEL AREA=   0.31
                  SHEAR FORCE FOR LC NO.1=   6.3863E 03
                  SHEAR FORCE FOR LC NO.2=  -3.8619E 03
          PAVEMENT SLAB
                  A(23)=  0.31              S(23)= 16.47
                  A(24)=  0.16              S(24)= 18.00
                  A(25)=  0.70              S(25)= 18.00
                  A(26)=  0.87              S(26)= 18.00
                  A(27)=  1.08              S(27)= 18.00
                  A(28)=  1.11              S(28)= 18.00

=========================== END T3FV DESIGN ==============================
```

Figure 48. Computer output, type T3FV detail design.

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                    RECTANGULAR STRUCTURAL CHANNEL
                          CROSS SECTION DESIGN
          ELASTIC ANALYSIS AND WORKING STRESS DESIGN ARE USED

      SPECIAL DESIGN PREPARED BY THE DESIGN UNIT AT HYATTSVILLE, MD.
                                  FOR

     EXAMPLE SPECIAL DESIGNS FOR STRUCTURAL CHANNEL TECHNICAL RELEASE
     JOAN FOR ESA --------- 2/29/72

              DESIGN PARAMETERS
  B= 24.00      HW1= 12.00      KO1= 0.80    FLOATR=  1.50   MFOUND= 100000.
 HT= 16.00      HW2=  1.50      KO2= 0.20    JOINTS= 40.00   GMOIST=    120.
 HB= 15.00      HWP= 12.00    KPASS= 1.25    MAXFTG= 12.00     GSAT=    140.
                               CFSC= 0.35      CFSS=  0.55

              DESIGN OF SPECIFIED TYPE FOLLOWS

              TYPE T3FV STRUCTURAL CHANNEL - TRIAL VALUES
  X=  3.00      TP= 30.00       XP= 18.00
 TT= 10.00      TB= 19.00       TS= 20.00  FTG PROJ=12.00   QUANT=  5.146

              TYPE T3FV STRUCTURAL CHANNEL - DETAIL DESIGN
  X=  3.00      TP= 30.00       XP= 18.00
 TT= 10.00      TB= 19.00       TS= 20.00  FTG PROJ=12.00   QUANT=  5.146

              STEEL REQUIREMENTS
          WALL
                A( 1)=  0.24               S( 1)= 18.00
                A( 2)=  0.24               S( 2)= 18.00
                A( 3)=  0.29               S( 3)= 18.00
                A( 4)=  0.15               S( 4)= 18.00
                A( 5)=  0.35               S( 5)= 18.00
                A( 6)=  0.27               S( 6)= 18.00
                A( 7)=  0.52               S( 7)= 18.00
                A( 8)=  1.05               S( 8)= 18.00
                A( 9)=  1.08               S( 9)= 18.00
                A(10)=  2.50               S(10)= 12.86
          BASE
                A(11)=  0.24               S(11)= 18.00
                A(12)=  0.24               S(12)= 18.00
                A(13)=  0.30               S(13)= 18.00
                A(14)=  0.41               S(14)= 18.00
                A(15)=  1.73               S(15)= 14.33
                A(16)=  1.17               S(16)= 18.00

                A(17)=  0.48               S(17)= 18.00
                A(18)=  0.54               S(18)= 16.83
                A(19)=  0.48               S(19)= 18.00
                A(20)=  0.24               S(20)= 18.00
                A(21)=  0.48               S(21)= 18.00
                A(22)=  0.24               S(22)= 18.00

          SHEAR CONNECTION
                REQD TENSION STEEL AREA=   0.31
                SHEAR FORCE FOR LC NO.1=   6.7415E 03
                SHEAR FORCE FOR LC NO.2=  -1.6750E 03
          PAVEMENT SLAB
                A(23)=  0.72               S(23)= 18.00
                A(24)=  0.36               S(24)= 18.00
                A(25)=  0.72               S(25)= 18.00
                A(26)=  0.36               S(26)= 18.00
                A(27)=  0.72               S(27)= 18.00
                A(28)=  0.36               S(28)= 18.00

============================ END T3FV DESIGN ==============================
```

Figure 49. Computer output, type T3FV detail design.

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                       RECTANGULAR STRUCTURAL CHANNEL
                            CROSS SECTION DESIGN
            ELASTIC ANALYSIS AND WORKING STRESS DESIGN ARE USED

        SPECIAL DESIGN PREPARED BY THE DESIGN UNIT AT HYATTSVILLE, MD.
                                     FOR

       EXAMPLE SPECIAL DESIGNS FOR STRUCTURAL CHANNEL TECHNICAL RELEASE
       JOAN FOR ESA --------- 2/29/72

                DESIGN PARAMETERS
  B= 24.00        HW1=  0.0       KO1= 0.80     FLOATR=  1.50    MFOUND= 100000.
 HT= 16.00        HW2=  0.0       KO2= 0.20     JOINTS= 40.00    GMOIST=    120.
 HB= 15.00        HWP=  0.0     KPASS= 1.25     MAXFTG= 12.00      GSAT=    140.
                                 CFSC= 0.35       CFSS=  0.55

                DESIGN OF SPECIFIED TYPE FOLLOWS

                TYPE T1S STRUCTURAL CHANNEL - TRIAL VALUES
 SB= 12.00        ST= 15.00       EB= 15.00         ET= 23.00
 TT= 10.00        TB= 12.00       TS= 13.00    FTG PROJ= 0.0     QUANT=  2.285

                TYPE T1S STRUCTURAL CHANNEL - DETAIL DESIGN
 SB= 12.00        ST= 15.00       EB= 15.00         ET= 23.00
 TT= 10.00        TB= 12.00       TS= 13.00    FTG PROJ= 0.0     QUANT=  2.285

                STEEL REQUIREMENTS
           WALL
                   A( 1)=  0.24                S( 1)= 18.00
                   A( 2)=  0.12                S( 2)= 18.00
                   A( 3)=  0.86                S( 3)= 18.00
                   A( 4)=  0.67                S( 4)= 18.00
                   A( 5)=  1.11                S( 5)= 18.00
                   A( 6)=  0.95                S( 6)= 18.00
                   A( 7)=  0.56                S( 7)= 18.00
                   A( 8)=  0.84                S( 8)= 18.00
                   A( 9)=  0.29                S( 9)= 18.00
                   A(10)=  1.04                S(10)= 11.46
           BASE
                   A(11) - A(16) DO NOT EXIST SINCE FTG=0

                   A(17)=  0.31                S(17)= 18.00
                   A(18)=  1.04                S(18)= 18.00
                   A(19)=  0.42                S(19)= 18.00
                   A(20)=  0.16                S(20)= 18.00
                   A(21)=  0.39                S(21)= 18.00
                   A(22)=  0.16                S(22)= 18.00

           STRUT STEEL
                   REQD TENSION STEEL AREA = 2.15
                   REQD COMPRES STEEL AREA = 2.15

           EDGE BEAM STEEL
                   STIRRUPS REQUIRED, USE AT LEAST
                       NO. 3 AT   9.7 IN. CC
                    AT D DISTANCES FROM FACES OF STRUTS
                   A( 1)=  0.85                P( 1)=  1.75
                   A( 2)=  1.02                P( 2)=  2.10
                   A( 3)=  3.64                P( 3)=  3.56
                   A( 4)=  4.41                P( 4)=  4.28
                   A( 5)=  0.72                P( 5)=  1.86
                   A( 6)=  0.86                P( 6)=  2.23
                   A( 7)=  3.54                P( 7)=  0.0
                   A( 8)=  2.77                P( 8)=  0.0
=============================== END T1S DESIGN ===============================
```

Figure 50. Computer output, type T1S detail design.

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                  RECTANGULAR STRUCTURAL CHANNEL
                       CROSS SECTION DESIGN
         ELASTIC ANALYSIS AND WORKING STRESS DESIGN ARE USED

     SPECIAL DESIGN PREPARED BY THE DESIGN UNIT AT HYATTSVILLE, MD.
                               FOR

    EXAMPLE SPECIAL DESIGNS FOR STRUCTURAL CHANNEL TECHNICAL RELEASE
    JOAN FOR ESA --------- 2/29/72

             DESIGN PARAMETERS
 B= 24.00       HW1= 12.00      KO1= 0.80    FLOATR=  1.50   MFOUND= 100000.
HT= 16.00       HW2=  1.50      KO2= 0.20    JOINTS= 40.00   GMOIST=    120.
HB= 15.00       HWP= 12.00    KPASS= 1.25    MAXFTG= 12.00     GSAT=    140.
                               CFSC= 0.35      CFSS=  0.55

             DESIGN OF SPECIFIED TYPE FOLLOWS

             TYPE T1S STRUCTURAL CHANNEL - TRIAL VALUES
SB= 12.00       ST= 15.00       EB= 15.00       ET= 26.00
TT= 10.00       TB= 21.00       TS= 22.00  FTG PROJ=10.40   QUANT=  4.990

             TYPE T1S STRUCTURAL CHANNEL - DETAIL DESIGN
SB= 12.00       ST= 15.00       EB= 15.00       ET= 26.00
TT= 10.00       TB= 21.00       TS= 22.00  FTG PROJ=10.40   QUANT=  4.990

             STEEL REQUIREMENTS
     WALL
                A( 1)=  0.26                S( 1)= 18.00
                A( 2)=  0.17                S( 2)= 18.00
                A( 3)=  0.32                S( 3)= 18.00
                A( 4)=  0.93                S( 4)= 18.00
                A( 5)=  0.38                S( 5)= 18.00
                A( 6)=  1.25                S( 6)= 18.00
                A( 7)=  0.44                S( 7)= 18.00
                A( 8)=  1.55                S( 8)= 18.00
                A( 9)=  0.50                S( 9)= 18.00
                A(10)=  2.83                S(10)= 13.30
     BASE
                A(11)=  0.26                S(11)= 18.00
                A(12)=  0.26                S(12)= 18.00
                A(13)=  0.26                S(13)= 18.00
                A(14)=  0.26                S(14)= 18.00
                A(15)=  1.05                S(15)= 18.00
                A(16)=  0.26                S(16)= 18.00

                A(17)=  0.53                S(17)= 18.00
                A(18)=  0.83                S(18)= 17.34
                A(19)=  0.75                S(19)= 18.00
                A(20)=  0.26                S(20)= 18.00
                A(21)=  0.94                S(21)= 18.00
                A(22)=  0.26                S(22)= 18.00

     STRUT STEEL
                REQD TENSION STEEL AREA = 3.70
                REQD COMPRES STEEL AREA = 0.0

     EDGE BEAM STEEL
                STIRRUPS REQUIRED, USE AT LEAST
                    NO. 3 AT  6.6 IN. CC
                 AT D DISTANCES FROM FACES OF STRUTS
                A( 1)=  1.18                P( 1)=  2.46
                A( 2)=  0.0                 P( 2)=  0.0
                A( 3)=  5.24                P( 3)=  5.38
                A( 4)=  0.0                 P( 4)=  0.0
                A( 5)=  0.72                P( 5)=  2.83
                A( 6)=  0.0                 P( 6)=  0.0
                A( 7)=  0.0                 P( 7)=  0.0
                A( 8)=  4.71                P( 8)=  0.0

============================== END T1S DESIGN ==============================
```

Figure 51. Computer output, type T1S detail design.